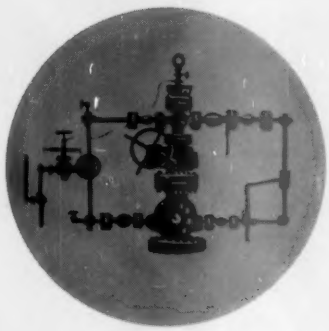
30TH
FALL
MEETING



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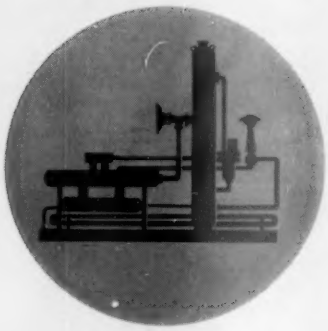
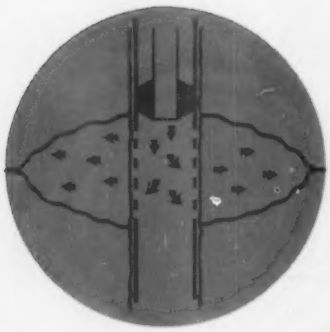
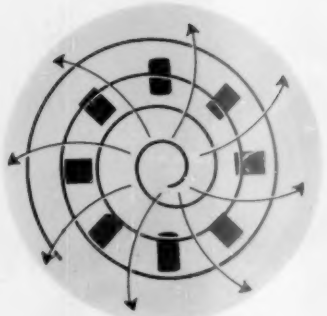
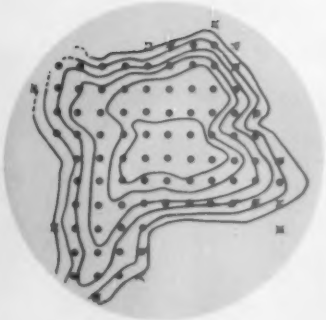






JOURNAL OF PETROLEUM TECHNOLOGY



SEPTEMBER 1955

PETROLEUM BRANCH

WHAT'S THE SHAPE OF THE HOLE?

There comes a time on every well when "it's money in the bank" if you know the shape of the hole. A cavity here . . . a mud cake there . . . in other places the hole to gauge. All this, you see at a glance on the **Schlumberger Section Gauge** Survey—information which is often essential for testing, cementing and log interpretation.

The Schlumberger Section Gauge gives you details about the hole size to a diameter of 36 inches. Its dependable operation has guided thousands of operations to successful completion. When in doubt, call your Schlumberger Engineer. It's best to be sure on every survey.

SCHLUMBERGER
Well Surveying Corporation
THE EYES OF THE OIL INDUSTRY

PAY ZONE···of a Service Policy

HALLIBURTON
OIL WELL CEMENTING
COMPANY
DUNCAN, OKLAHOMA

Daybreak dims the brilliance of oil field lights... a distant rooster challenges the rumble of the rigs... and the morning mist rolls aside for a huge red and silver truck. Service companies, also, work a twenty-four hour tour. Service is the esprit de corps of a Halliburton camp. Halliburton long ago adopted the policy of service beyond the fee, service above all. And this policy has spread thoroughly to every one of Halliburton's 250 camps. Here, in the center of practically every oil patch, is the pay zone of Halliburton's service policy. And here, too, research is one of our most important services.

"PROGRESS IN SERVICE THROUGH RESEARCH"

'Way out in West Texas where the big core grows, Core Lab has put into service a fleet of *Freeze Trucks.* Completed only recently, these sparkling new dry ice units are already in great demand.

In 1949, before the advent of widespread diamond coring with routine recovery of up to fifty feet of large diameter core, Core Lab inaugurated its Frozen Core Service with the now-familiar Freeze Box. A supply of dry ice soon became standard "equipment" in each local lab.

Today's Core Lab Freeze Truck provides special five-foot tempered aluminum trays for receiving core on the rig floor. The trays are then placed in proper sequence in the truck-mounted, insulated chest (containing 250 pounds of dry ice) and rapidly transported to the nearest lab where analysts begin processing samples directly from the convenient containers. The overall result — more efficient preservation of critical fluid contents and less handling of the core.

From thirty-one installations covering all active exploration areas, Core Lab keeps an eye out for ideas that keep services "up to snuff".

Whether it's core analysis, well logging, reservoir fluid analysis, or engineering and consulting, Core Lab is continually proving out techniques and procedures to do your next job even better.

CORE LABORATORIES, INC.
801 CORE STREET, DALLAS, TEXAS

CORE LAB
PETROLEUM RESERVOIR ENGINEERING

DALLAS, HOUSTON, CORPUS CHRISTI, MIDLAND, ABILENE, SAN ANTONIO, TYLER, TULSA, FORT WORTH, WICHITA FALLS, SHERMAN, OKLAHOMA CITY, ARDMORE, BARTLESVILLE, PAMPA, ARKANSAS CITY, GREAT BEND, NEW ORLEANS, SHREVEPORT, HATTIESBURG, LAFAYETTE, DENVER, BAKERSFIELD, CASPER, BILLINGS, WORLAND, STERLING, EL DORADO, LUBBOCK, FARMINGTON, LOVINGTON, MONAHANS, SAN ANGELO; CALGARY, EDMONTON, REGINA.

JOURNAL OF PETROLEUM TECHNOLOGY

SEPTEMBER, 1955

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Journal of Petroleum Technology is published monthly by the Petroleum Branch, American Institute of Mining and Metallurgical Engineers, Inc., at 800 Fidelity Union Bldg., Dallas 1, Tex. Entered as second class matter at the Post Office at Dallas, Tex. Domestic Subscription: North, South, and Central America, $8; foreign, $10; to AIME members, $6 (or $4 if in combination with subscription to either Journal of Metals or Mining Engineering). Single copies, 75 cents in U. S. A., $1, foreign; special issues, $1.50. Registered cable address, AIME. Printed in U. S. A. Views expressed herein are not necessarily those of the AIME.

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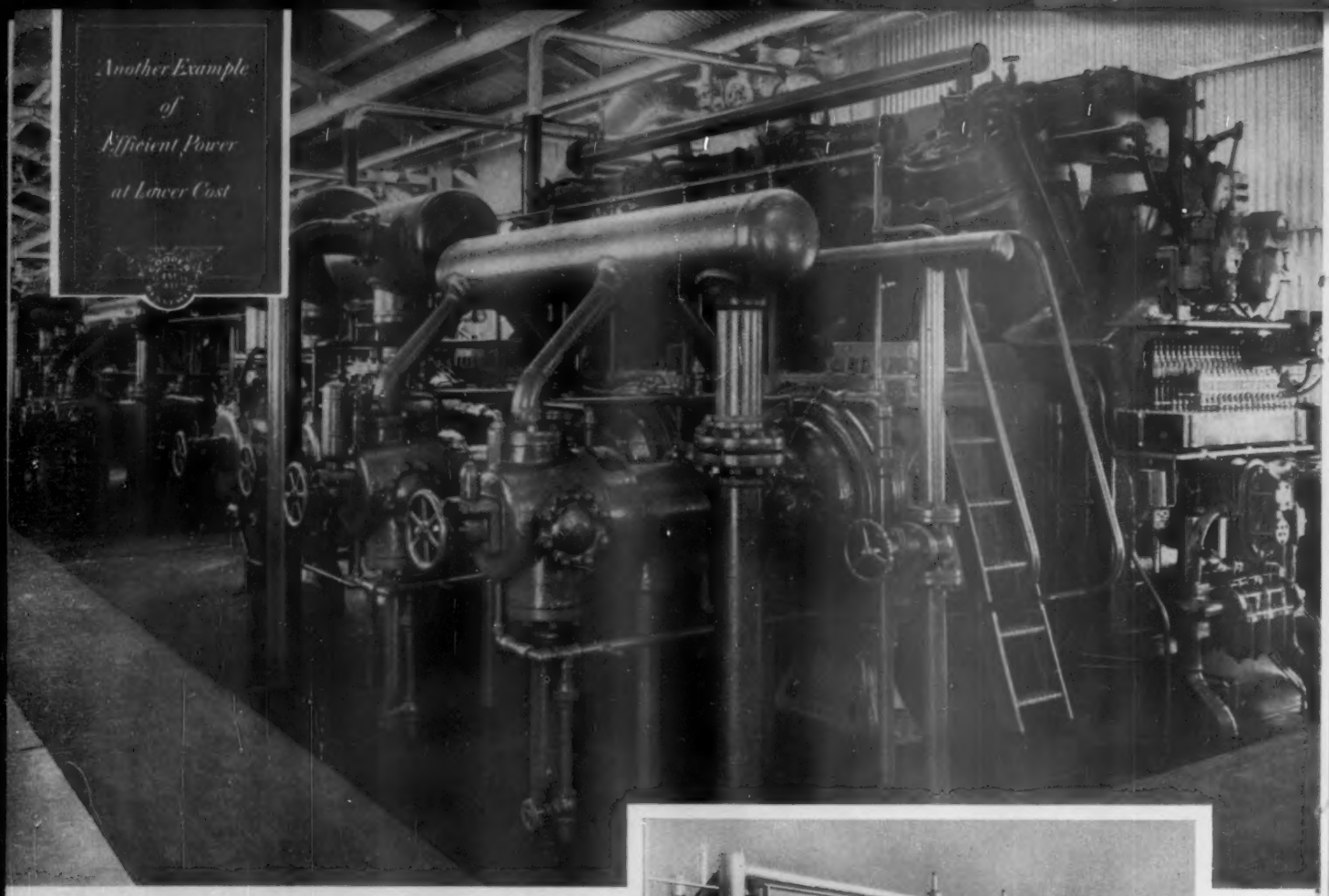
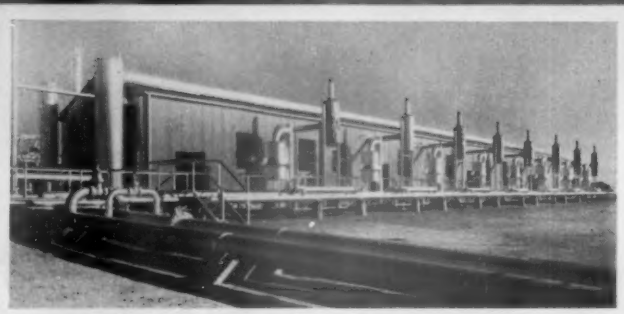
Another Example of Efficient Power at Lower Cost





Line-up of eight Cooper-Bessemer 8- and 10-cylinder compressors at Ballinger, Texas. Two GMV-8-TF's are used for propane refrigeration, and injection, while the remaining six compressors are used for plant process gas.

The compact Runnels natural gasoline plant at Ballinger, Texas, contains five Cooper-Bessemer 880 hp GMV-8-TF's, and three 1100 hp GMV-10-TF's, totaling 7700 dependable compressor horsepower. The plant was designed by Messrs. F. M. Seibert and W. H. Woods of Runnels Gas.

Dependability plus . in the GMV story at Runnels Gas

YES, efficient, trouble-free performance. That's the experience of Runnels Gas Products Company with the eight Cooper-Bessemer GMV's recently installed at their Ballinger, Texas plant. But that's only part of the story . . . expected and counted on with these modern V-angle compressors.

Runnels Gas, a subsidiary of Union Sulphur and Oil Corporation, uses these GMV's for process gas, propane refrigeration, and gas injection in this new natural gasoline plant of theirs. And they, like so many Cooper-Bessemer customers, have made a point of expressing appreciation for the detailed installation recommendations of C-B service personnel . . . and also for the availability and rapid delivery of needed spare parts. This sort of cooperation is mighty important in *any* kind of engine or compressor application.

Next time your plans call for compressors up to 2500 bhp, check on Cooper-Bessemers.

MOUNT VERNON, OHIO

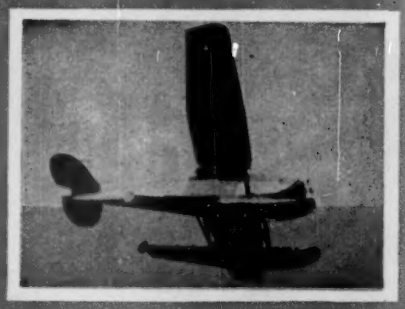
COOPER-BESSEMER

GROVE CITY, PENNA.

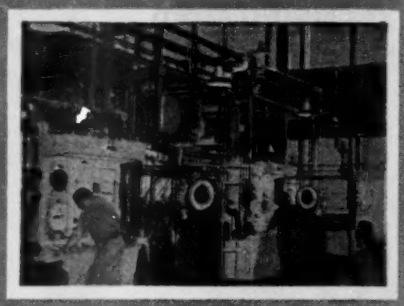
New York City • Seattle, Wash. • Bradford, Pa. • Chicago, Ill. Houston, Dallas, Greggton, Pampa and Odessa, Texas Washington, D. C. • Shreveport, La. • San Francisco, Los Angeles, Calif. • St. Louis, Mo. • Gloucester, Mass. • New Orleans, La. • Tulsa, Okla. • Cooper-Bessemer of Canada Ltd., Edmonton, Alberta—Halifax, Nova Scotia.

DIESELS • GAS ENGINES • GAS-DIESELS • ENGINE-DRIVEN AND MOTOR-DRIVEN COMPRESSORS

8 reasons why Tretolite offers superio SERVICE



1 *Facilities to insure prompt service*



2 *Superior manufacturing equipment*

3 *Continuing research and development*

4 *On-the-job development program*

5 *Adequate stocks, conveniently located*

6 *Offices or engineers located in all petroleum areas*

7 *Expert, experienced service personnel*

8 *A variety of helpful products and services*

DEMULSIFYING
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WATER CLARIFICATION
CORROSION PREVENTION
PRODUCTIVITY IMPROVEMENT
PARAFFIN REMOVAL
SCALE PREVENTION
BACTERICIDES

TRETOLITE COMPANY
Tret-O-litE
SAINT LOUIS LOS ANGELES

TRETOLITE COMPANY

APPROVAL FROM THE FIELD

of the LUFKIN A LINE

The LUFKIN Air-Balanced Unit has been accepted as a member in good standing of the LUFKIN line of superior pumping equipment as indicated by the many repeat orders we are receiving from satisfied customers.

EXPLANATION OF UNIT DESIGNATION

- A—FOR AIR COUNTERBALANCE
- 912D — GEAR REDUCER (912,000 IN. LB. PEAK TORQUE) DOUBLE REDUCTION
- 144—MAXIMUM STROKE (144 INCHES)
- 35—PEAK POLISHED ROD CAPACITY (35,000 LB.)

AVAILABLE FOR QUICK DELIVERY IN THE FOLLOWING SIZES:

*A-912D-144-35
A-912D-120-35
A-912D-120-30
A-640DB-144-35
A-640DB-120-35
A-640DB-120-35
A-456DB-120-30
A-456DB-100-30
A-320D-100-27
A-320D-86-27
A-228D-86-23
A-228D-74-23
A-160D-74-20
A-160D-64-20
A-114DA-64-16
A-114DA-54-16
A-80DB-54-16

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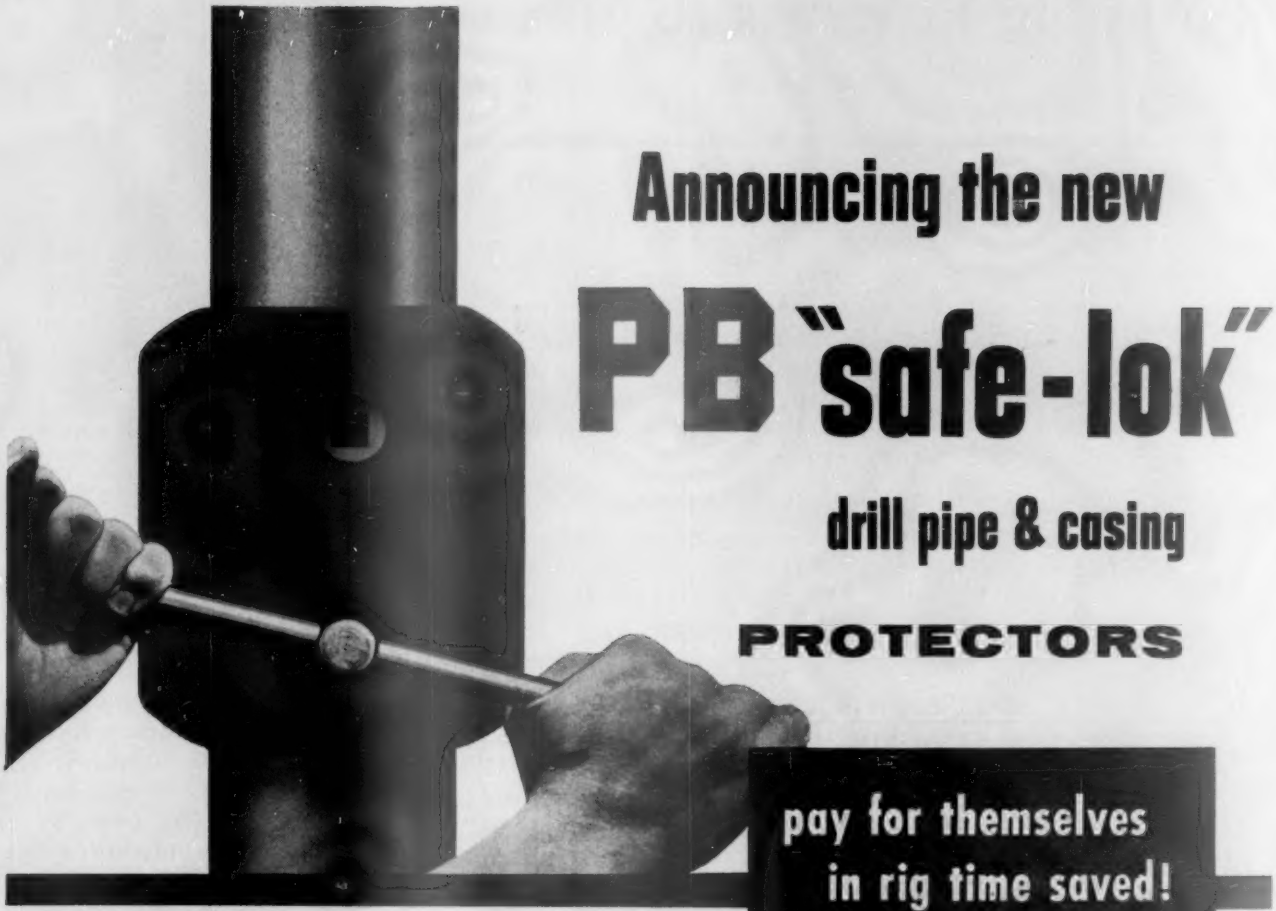
Lufkin equipment in Canada is handled by THE LUFKIN MACHINE CO., LTD., 14321 108th Avenue, EDMONTON, ALBERTA, CANADA



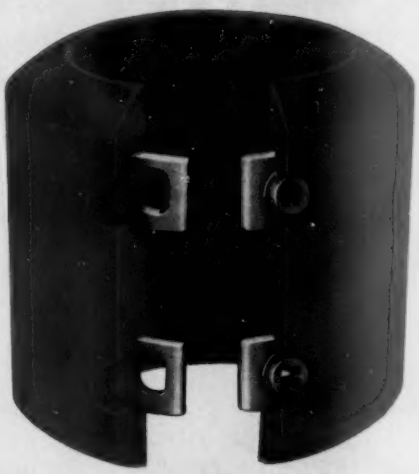
Announcing the new

PB "safe-lok"

drill pipe & casing

PROTECTORS

pay for themselves in rig time saved!



Quickly installed or removed by your own crew!

New PB Safe-Lok Protectors (formerly known as Vetco OFF-N-ON Protectors) pay for themselves in rig time saved. Your regular drilling crews can install or remove them—in seconds—using just a simple wrench. You eliminate the time and trouble of laying down and picking up rubbered pipe while drilling. You do away with special handling and storing of rubbered pipe and costly shipment of rubbered pipe from one drilling site to another.

New PB Safe-Lok Protectors have all the time-tested stamina of PB oil field rubber products *plus* this patented, money-saving installation and removal feature. Safe-Lok Protectors are available in a range of sizes and lengths for drill pipe sizes from 3½" to 5½". Ask any BJ-PB field sales engineer or write to address below.

results talk!

Lease X-41. Set 1160' of 11¾" casing. Used forty Safe-Lok Protectors (size 4½" x 8") from 1200' to 12,564'. Made 96 round trips—eliminated laying down 6 to 15 singles each trip. Saved 15 to 25 minutes per trip or a total of 28 hours. At $60 per hour, this one hole saved $1680!

EXPORT OFFICE

BYRON JACKSON CO.
Suite 10, 580 Fifth Avenue
New York 36, New York

BJ

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P.O. BOX 2493, TERMINAL ANNEX LOS ANGELES 54, CALIFORNIA
Sales engineers in all principal oil fields

Pumping Progress Report

FOR HYDRAULIC ENGINEERS

An advertisement prepared by the Aldrich Pump Co., Member of Hydraulic Institute, U.S.A.

PUMPING LIQUID BUTANE AND PROPANE is a typical operational headache successfully handled by the Aldrich Pump Company Engineers. It was a particularly tough pumping problem for one large pipe line company; they had to move butane 186 miles — from a Texas oil field to a Gulf Coast refinery.

PUMPING LIGHT-GRAVITY FLUID AT HIGH PRESSURES required the positive displacing action of conventional reciprocating pumps plus the flexibility of capacity provided by centrifugals. And Aldrich Engineers knew the answer — the Aldrich-Groff Controllable Capacity "POWR-SAVR" Pump.

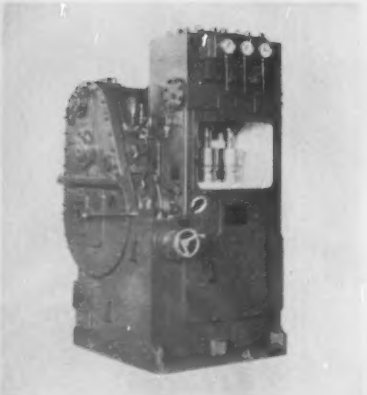
STEPLESS STRAIGHT LINE CONTROL OF CAPACITY, from zero to rated maximum output, was possible with the "POWR-SAVR". Pump delivery was automatically controlled to suit varying requirements and power consumption became nearly proportional to the rate of output, affording desirable power savings.

SURGE TANKS WERE ELIMINATED, due to the "POWR-SAVR's" ability to meet immediate changing line conditions. This eliminated associated evaporation losses, co-mingling of different batches, and much of the danger of handling highly flammable material. Gone, too, was the need for bypassing to handle excess quantities of pump output.

UPRIGHT DESIGN of the "POWR-SAVR" places discharge valves directly over the plungers and inlet valves at one side. Efficient valve action permits the pump to operate at the high rate of 240 rpm. Another design feature was the use of porcelain plungers, reducing packing and leakage troubles.

THE ALDRICH PUMP COMPANY has been solving the difficult pumping problems of American industry since 1902. We've never turned down a challenge — many of yesterday's tough pumping problems are today routine.

DATA SHEET 65A, describing the Aldrich-Groff Controllable Capacity "POWR-SAVR" Pump will be sent to you on request. Or our representative will be glad to call. Address your request to: The Aldrich Pump Company, 7 Gordon Street, Allentown, Pa.



Aldrich-Groff Controllable Capacity "POWR-SAVR" Pump suitable for pumping butane and other light-gravity fluids.

...for your tough pumping problems specify ALDRICH

This machine is ideal for pumping light-gravity fluids at medium and high pressures. It combines features of superior efficiency and positive displacing action of reciprocating pumps with the flexibility of capacity of centrifugal pumps. A unique, reliable mechanism controls the plunger-stroke from zero to rated output without change of speed of power source, providing desired savings in power plus top efficiency.

Typical Applications for the Aldrich-Groff "POWR-SAVR" Pump:

Pipe Line Service — Process Charging
Boiler Feeding — Oil-burner Supply

Write for Data Sheet 65A, describing the features of the "POWR-SAVR" Pump. Or, if you prefer, our representative will be glad to call.

THE ALDRICH PUMP COMPANY

Originators of the Direct Flow Pump
30 PINE STREET
ALLENTOWN, PA.
Representatives in principal cities

Visco

CONSISTENTLY EFFICIENT OIL FIELD CHEMICALS

FORMATION WATER CONTROLLED

SOS (Slurry Oil Squeeze)—new DOWELL service for oil and gas wells—stopped water production completely, aided effectiveness of fracturing

Dowell's new Cementing Service—SOS (Slurry Oil Squeeze)*—is designed to provide a fast, low-cost means of ending troublesome water encroachment in oil and gas wells.

Production records have proved the effectiveness of SOS. For instance, one oil well completed in a sandstone formation was producing 200 barrels of salt water and only 3 barrels of oil per day. SOS by Dowell stopped the water completely and paved the way for a small gallonage Sandfrac† treatment. After the fracturing treatment, the well pumped 75 BOPD with no water.

Dowell engineers premix the entire batch of slurry for SOS in truck-mounted, paddle-mixing tanks. This equipment is specially designed to mix a uniform slurry—even in small batches. High-pressure triplex pumps are used to inject the slurry into the formation. The SOS slurry is made up of portland cement, a Dowell surface tension reducing agent and a non-aqueous carrying medium—for example, specially blended oils. The cement sets up only when contacted by formation water.

Contact the nearest Dowell office for more information on SOS or any of Dowell's many oil field services—in Venezuela, contact United Oilwell Service, S.A. Or write Dowell Incorporated, Tulsa 1, Oklahoma, Dept. I-15.

*A Service Mark of Dowell Incorporated
†Sandfrac is a registered service mark of Dowell Incorporated

services for the oil industry

DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY

This is the second of a series of editorials to be written on "What AIME Means to Me" by long-standing members of the Petroleum Branch, AIME.

EDITORIAL

WHAT AIME MEANS to ME

C. V. MILLIKAN
MEMBER AIME

AMERADA PETROLEUM CORP.
TULSA, OKLA.

"Opportunity," probably more than any other one word, expresses the meaning of membership in AIME. Opportunity to meet other petroleum engineers. Opportunity to hear technical papers and discussions. Opportunity to present technical papers.

An engineer's greatest asset is technical friends with similar problems. No engineer is so proficient that he cannot benefit from a discussion of both his simple and perplexing problems, and experiences with other engineers who are having similar experiences. Of equal value is to know of problems of others in order to anticipate and forestall problems that may become his. An engineer without problems ceases to be an engineer.

The AIME Classroom

An education can be obtained without attending a college or university, but certainly the classroom lectures and campus associations greatly increase the breadth and depth of an education. Similarly, while an engineer may keep abreast of technical progress by reading the technical literature, the attendance of AIME meetings and the discussions of papers presented provide the "classroom" for his advancement as an engineer. The ensuing informal discussions, which are always an integral part of such meetings, add much breadth and depth to the formal programs.

Presenting a Paper

The opportunity of presenting a paper before a technical meeting cannot be fully appreciated by an engineer who has not had such experience. Engineers, like others, are too prone to rely on generally accepted statements. An investigation of a problem may be made and the results studied only to the extent necessary to reach a conclusion. Reasoning may not be thorough. If the results are to be presented as a technical paper, it is probable that much broader and deeper thought will be given to the problem and additional work may be required to clarify or confirm the conclusions before they are presented for critical consideration by other engineers. A contribution to the technical literature gains for him stature among his fellow engineers and associates and a greater self-confidence through the completion of original work. Presenting an engineering paper before an engineering society is truly the culmination of opportunity.

No engineer is an island unto himself. Membership in AIME is opportunity for technical intercourse with fellow engineers, opportunity for deeper meaning of technical papers and opportunity to present technical papers. In short, AIME *is* opportunity. ★★★

ENGINEERS AS MANAGERS

J. C. DONNELL II | THE OHIO OIL CO.
FINDLAY, OHIO

New Emphasis on Management Training

Hardly a week passes in which an invitation does not come from some university or management consultant firm to send some of our prospective management personnel for exposure to the newest concepts in the arts of administration. Seldom do we pick up a periodical, even of the popular variety, that does not contain an article about some company's program for management development. Your bookcases, like mine, surely have received more than their share of books on how to become a more effective administrator, a better manager, or an executive that gets the job done.

This unprecedented emphasis on managerial development has been prevalent since the close of World War II, and has long since passed the fad stage. Why is this? American industry has always managed to develop its leaders in the past; what is it that's different today?

Probably it stems from the increasing size and complexity of industry. Great technological developments, for which the engineers are partly responsible, have contributed to this complexity and growth. We have also inherited some factors from the past, the depression of the 30's and war in the 40's with their respective unemployment and shortage of workers played their part in disrupting the transition of American industry to its present status. The fact that in the past 25 years government has come to play an ever increasing role in American industry, exercising much greater regulation and control, has also had its effect. Now with the return to a highly competitive era, we are all concerned with the problem of getting more people to manage capably and to perpetuate our enterprises.

No Stereotype for Successful Managers

In all the discussion that has developed over the past few years, it is obvious that many people think a manager or an executive has certain specific traits easily recognized which can be developed by education, training, and experience. This is not true, for there is no stereotype of successful managers. Managers vary just like other people do. Certainly there is no reason why all the characteristics of managers at different levels should be similar, and why shouldn't they vary from company to company and industry to industry and from time to time? American industry, and the oil industry in particular, must depend on all its professional and highly skilled employees as a reservoir of managers today and increasingly so in the future.

On this basis, undoubtedly the engineering profession will provide its share of these managers. In searching for managers, our criterion should not be any arbitrary traits or qualifications, but rather "what can a man accomplish."

Performance and the Intangibles

What a man can accomplish, refers specifically to "performance." Performance stems from certain skills combined with those basic characteristics universally required of any successful individual. Included in these basic characteristics are such intangibles as courage, perseverance, integrity, and general temperament. These characteristics are not only important to individuals who are managers, but to people generally. As a matter of fact, they help to shape our philosophies, attitudes, and our every day life. Given these characteristics, which vary with individuals, and which are not a mark of any specific profession or trade, it has been observed that certain skills are essential in getting a job done. These may be classified as technical proficiency, ability to work with other people, and the capacity to envision an enterprise in its entirety.

Technical proficiency involves specialized knowledge and generally has to do with methods, procedures, processes, or techniques. It requires analytical ability within a particular speciality and facility in the use of tools and techniques of a specific discipline. In short, technical proficiency is concerned with "things"—the physical and chemical world. An engineer performing the specific function for which he was trained is a good example. You, as petroleum engineers, are all intimately acquainted with technical proficiency.

The Second Skill

The second skill required in today's industry is the ability to work with, and through, other people. In contrast to technical proficiency, which is concerned with things, this second skill is concerned with human beings. This skill is revealed by the manner in which individuals behave with superiors, equals, and subordinates. If this skill is highly developed in an individual, he is aware of not only his own attitude and prejudices

The president of Ohio Oil Co., J. C. Donnell II, delivered this talk at the Petroleum Branch Dinner held at the 1955 AIME Annual Meeting.

about other individuals and groups, he also recognizes the existence and validity of viewpoints which may differ from his own. In working with other people he must be able to communicate to them, in their own context, what he means by his behavior.

This skill must be developed to the point where it is a natural, continuous activity, and the individual acquires a sensitivity which must almost be played by ear.

The Third Skill

The third skill — the capacity to envision an enterprise in its entirety — involves recognizing the importance of each part of an organization to another and the relationship of these parts to the whole. In a broader sense, the concept extends to an appreciation of the relationship of the enterprise itself to the industry of which it is a part, the community in which it operates, and even its effect on the political, social, and economic forces of the nation. It also encompasses an understanding of the effect of these same forces on the enterprise and its parts, and also includes a proper evaluation of technical proficiency and the human aspects which are involved.

Now this third skill is not merely perceptive, it also involves the ability to translate all skills into effective action. This is the essential ingredient which characterizes the entrepreneur—a word which has been lost sight of in the great discussions regarding the development of managers.

Application of the Skills

The application of these three skills varies in importance with each level of an enterprise. At the level in which production takes place, that is, in the drilling of a well or its operation, and in the plant or factory, technical proficiency undoubtedly has its greatest importance. Without a firm foundation in technical proficiency, the entire structure would be imperiled. Technical proficiency is indispensable to efficient operation and to progress. It is here that engineers play their essential role.

In American industry, advancement generally means changing one's occupation. In other words, when an engineer is promoted even to a position which involves supervising and directing other engineers, he is no longer just an engineer—but a manager, since by definition a manager is one who directs the activities of others. The moment he assumes this responsibility no longer does his progress depend solely on his technical proficiency; he must begin to employ more of his ability to work through other people. While technical proficiency may still be important to him in working with engineers, when he enters into operations where he must direct the efforts of people other than engineers, the need for his technical proficiency recedes much farther in importance.

Later, if an engineer should be placed in charge of a district or a plant, he needs to implement his ability to influence people favorably and, in addition, he must develop his capacity to view the part his operation plays in the entire enterprise. As he assumes responsibility for more people, more operations, and more functions, he begins to rely more and more on this capacity and the ability to get things done through others and less and less on his technical proficiency.

The Difficulty of Engineers Becoming Managers

There is no need at this time to discuss the first skill mentioned. Our engineering schools have done and are doing, a good job in turning out well-trained engineers. Their technical proficiency has been recognized in all industry. The petroleum industry in particular owes a great deal to its engineers—but my topic is engineers as managers, and *there seems to be some difficulty in moving engineers into positions of management.*

This difficulty apparently stems from the fact that engineering is a specialized application of scientific principles. Engineers must devote many years in becoming expert in their field, and one of the contributions to the difficulty is that engineers carry their specialization to some extreme. Even in the petroleum industry we no longer have just petroleum engineers—but reservoir engineers, secondary recovery engineers, and mud control engineers. Each of these specialties provides an important service in the production of crude oil, but they are quite far removed from the talents required in managing an enterprise as complex as crude oil production—let alone the other functions of the petroleum industry.

The training of a petroleum engineer which is directed toward making him technically proficient necessarily instills the scientific method. This means basically that nothing can be taken for granted and all data and information are subject to examination. As engineers ascend the pyramid of management they find this physically impossible to do. They have to depend on subordinates to perform this essential task, and apparently there is some difficulty in adjusting to the change.

Furthermore, engineering training develops self-reliance and an engineer learns to work on his own. This is no doubt a virtue, but when developed to an extreme an individual often becomes a "lone-wolf." Engineers with this tendency have difficulty in adjusting to managerial responsibilities because a manager necessarily must work with other people.

Another hindrance which engineers encounter in becoming managers is their inclination toward perfection. This is not meant to disparage the desire for perfection, but in the business world time is often important and sometimes management cannot wait for perfection.

The foregoing problems of engineers in becoming managers can be summarized by saying that managers must continually work with intangibles. This situation, we must admit, is quite foreign to the background of the usual engineer. Quite often engineers underestimate the importance of attitudes, emotions, traditions, and prejudices which cannot be measured. As a consequence, they tend to deal with those things which can be solved by logic alone. Yet the non-logical is often the crux of many business problems.

Petroleum Engineers Specifically

So far this discussion has been confined to engineers in general and this audience is composed of petroleum engineers. That which was said in the previous paragraph was not meant disparagingly nor to discourage you, but only to acquaint you with some of the problems which an engineer faces in becoming a manager. We cannot lose sight of the fact that many petroleum engineers have become successful managers and executives in our industry. In this regard, it should be pointed out that invariably these men have taken every opportunity to broaden themselves. *My message for those of you who wish to advance as managers is that you should strive continually to become familiar with the problems of human behavior and the many facets of the petroleum industry.*

This industry, it seems, has always been faced with

important issues. Today it is the Natural Gas Act. During the 30's it was conservation. Many of the petroleum engineers who became managers obtained their broadening experience in connection with the conservation issue. During the time when this issue was being clarified, petroleum engineers were called upon to work with many people in other professions and at different levels of management. They participated in negotiations, they necessarily became thoroughly familiar with property rights, and they learned that in a practical sense compromise is essential.

During the war years, engineers became involved in many extraordinary activities. They had to call on their ingenuity to keep equipment operating beyond its normal life span. They found how important their dependence was on equipment suppliers, and they definitely came in contact with the problems involved in federal regulation.

The petroleum industry seems to turn out a prolific amount of literature. Certainly enough is written and spoken with regard to issues so that engineers can keep abreast of developments. This they should do, even if they do not get involved directly in the natural gas controversy. This industry is big enough and varied enough to be almost sure that important issues will always be confronting us. The engineers should always be prepared to assist in these conflicts, and they will find as an important by-product that they will be emerging into the field of management.

Avenues of Management Training

There are many avenues available to the engineer who wishes to broaden himself and enter or rise in the field of management. The engineering schools connected with our universities have for some time recognized that engineering training should be supplemented by development in the humanities. They have instituted courses to help correct what they believe have been shortcomings in their curriculum.

While engineers may take a leave of absence to return to universities and supplement their education, it is often impractical to do so. They have been generally disciplined enough, however, to warrant their own study of the arts, economics, psychology, accounting, and other fields, and there is no reason why these studies should not be pursued.

More important, however, and certainly much more practical, is the opportunity for participating in industry affairs where discussions of a variety of problems are an education in themselves. For example, a petroleum engineer when attending trade association meetings should not limit himself to attending production sessions. By mixing with his counterparts in refining, pipelining, and marketing, he will find that his own activity assumes greater significance.

Fundamentally any broadening of the petroleum engineer should be self-generated. However, many companies provide programs designed to assist the engineer in this direction. The Ohio Oil Co. has no formal program for training new petroleum engineers, but the company is quite proud of the results obtained by having them spend their first year of service working with operating men. While the company believes that this early experience gives them a lasting impression on the practical problems which are to be faced, the main purpose is to determine whether they can get along with our operating people.

Advancement Without Becoming Managers

Engineers who enter management are not doomed to a life devoid of satisfaction and filled with frustration. Many well-adjusted managers have risen from the ranks of petroleum engineers and have become effective executives.

On the other hand, engineers should not necessarily have to enter management to advance. There have been many examples of good engineers who have entered the managerial ranks not because they were interested in management but because it seemed to them the only road to advancement. No doubt this road has in the past been much more lucrative. Reverting to an earlier comment, an individual should be judged by his performance—and compensation should be adjusted on the basis of the individual's contribution to the progress of his company.

Management's Responsibility

It is essential for present-day management to appraise its personnel, including engineers, periodically and to counsel with them. By means of these appraisals it can better be determined which men should remain in engineering and which ones should be provided with opportunities in management and elsewhere.

Managements should also accept their responsibility for creating the proper environment for all these men to grow. This should not be looked upon merely as a task that has to be done, but rather as an opportunity to help others attain greater fulfillment in their work lives. In accomplishing this phase of their responsibilities, managements will find one of their finest rewards.

Each man, regardless of his position, should contribute fully and to the best of his abilities to the common good of the company. In doing this, each individual can be expected to develop the team spirit which is necessary for the advancement of the group with which he is connected. Undoubtedly in the competition and struggle which goes on within our organizations, certain individuals emerge on their own right as managers. In other words, the various groups within an organization recognize superior performance and actually select their own leaders. Managements, contrary to popular belief, do not pick but rather acknowledge these chosen leaders.

Conclusions

The oil industry being large, varied, and complex, employs a multitude of talents to perform its basic functions. All of these talents are necessary for the progress of the individual units in the industry, and there will no doubt be greater opportunities for advancement both in management and in specialized fields.

In the rise toward top-level management positions, petroleum engineers will have to demonstrate by performance that they are as capable as the other specialized personnel. They must contend not only with the geologists and lawyers and operations men within the production branch of the industry, but also with engineers from the other branches and with every profession now contributing to the industry. They must also face the competition which will stem from younger men emerging from our universities well trained in engineering and perhaps with additional training in the humanities.

Undoubtedly petroleum engineers will effectively compete with the many other well-trained, ambitious, and imaginative personnel, and that they will continue to provide their share of the industry's top-level managers.

★★★

FROM ENGINEER TO EXECUTIVE

T. C. FRICK*
MEMBER AIME

THE ATLANTIC REFINING CO.
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There is no fixed path to an executive's desk. As each individual has a different background and training, so he must travel a different path; but in each case an executive to be successful must adjust to his surroundings. Sooner or later while travelling the path towards an executive's desk, it is discovered that duplicate actions and decisions will not always produce duplicate results. The engineer, having been trained in the laboratory and mathematics class to expect duplicate results from duplicate actions, notices this conflict and finds he must make an adjustment to fit into an executive's surroundings. Changing to the surroundings of the executive sometimes requires considerable effort on the part of the individual. As someone once said, it is much easier to change a blueprint or a structure than the nature of the man working on it.

An engineer may take two samples of a core from an oil sand that have the same air permeability and test them time and again, duplicating the results with a fair degree of accuracy. This will prove that both samples have the same permeability to air and that Darcy's law for single phase flow is accurate enough to produce duplicate results. The same engineer can take two people of the same age and similar backgrounds and criticize both individuals, using identical words and voice inflections, and the results will be far from duplicated. To one individual the constructive criticism may mean praise and produce good will. To the other individual the same constructive criticism will be demoralizing and may produce ill feelings.

Most engineers can agree what it means and can understand Boyle's law of a perfect gas when they see the law expressed as a mathematical formula. Engineers will be in very close agreement on deviations from Boyle's law for any particular gas. However, when engineers read a statement such as "he was a wealthy oil man," they will probably fail to agree on what the statement means. Unlike the terms in Boyle's law, the important term "wealthy" in this statement is not defined. "Wealthy" is a relative term, and it has a different meaning to each individual who uses the term, because each individual has a different concept of what constitutes wealth.

*T. C. Frick is chairman-elect of the Petroleum Branch and will assume the chairmanship in Feb., 1956.

The Executive's Surroundings

If we want to be an executive, we have to change to an executive's surroundings. We have to adjust to these new surroundings or find ourselves in conflict with them. Psychologists tell us that it is hard to break away from our early training, but we know that people do change. They are flexible. Some adjust to current surroundings and new jobs with ease; others live in the past and in conflict with new surroundings, in which case change and adjustment are difficult.

As engineers in the petroleum industry, our training during our college days and our time during our first employment was mostly in dealing with things, such as physical laws, chemical laws, materials, and mathematics. As we move ahead in our course of employment, we soon find that we must spend some time communicating with people in addition to our engineering work. These communications are with our fellow workers and our supervisor, or, if we happen to be a supervisor, our subordinates. If we advance through supervisory ranks to more important managerial positions, we find that more and more of our time is spent with the broader issues of business, in dealing with intangible values, and in dealing with people.

Time vs Thoroughness of Treatment

Engineers are taught to seek facts, use the facts in their proper order, and report findings and results determined from the facts. This is as it should be. No change need be made in this respect in the advance towards a managerial position. Where business decisions must be made when all of the facts are not available or where intangible values are involved, we engineers run into difficulty and must adjust to new conditions in order to deserve the title of executive. There is a natural reluctance on the part of everyone to make a decision when the facts are not clear; however, business must go on and decisions must be made. Delay while obtaining facts may make the decision more accurate, but the business may have been lost due to the delay.

The executive is constantly faced with the problem of time vs the thoroughness of treatment of the problem before a decision is reached. Most engineers are trained along the paths of treating each problem thoroughly; and as they advance into management, they

must recognize the necessity for compromise between thoroughness of treatment and the element of time.

Estimating the Unknown Factors

Factors influencing management decisions are not always the same as in engineering decisions. Legal rights, moral responsibilities, and human decency often influence management decisions. When an engineer tackles the problem of designing equipment to lift oil from a specific well, he obtains such facts as depth from which fluid is to be lifted, quantities of oil and water to be produced, corrosiveness of fluids, sources of power, etc. Some factors may have to be estimated; that is, the engineer may have to use his best guess as to the quantities of fluid to be produced. Using the facts and estimates, the engineer will usually select the best alternative for lifting oil from the well, and will not be satisfied unless the best alternative is used. An executive must sometimes be satisfied with the second or even third best of economic alternatives, because people, governments, or even moral issues may be involved which prevent the selection of the best economic alternative.

Most executives, like engineers, can reach a sound conclusion and make the right decision if they have all of the necessary facts. It is the unknown factors that must be estimated by management that are different than those estimated by engineers. They are different because people are involved. A manager of an oil company considers all of the facts concerning the development program for an oil field and decides on a plan of action. That is, facts and recommendations from the company engineers, geologists, economists, and legal counsel are considered. Then the manager arrives at what he thinks is a sound plan for development of the field, which is not only good from his company's viewpoint but appears to be good from the viewpoint of the royalty owner and the state. Because people are involved, the manager may be faced with a ruling from the state regulatory commission that would prevent his development of the oil field as planned, or he may be faced with legal action from a royalty owner who thinks the manager's plan of development discriminates against his royalty interest and violates the terms of a lease. This may mean a revised plan of development which is not necessarily best for everyone, but it must be carried out in order to develop the oil field at all.

Still Want to Be an Executive?

It should be stated that to be successful as an engineer or scientist it is not necessary that you become a manager or an executive. Some of the world's most successful engineers and scientists have never entered the field of management. Achievement in the field of science and engineering is just as important to industry and the welfare of our United States as achievement in the field of management. An engineer who follows his training and practices his profession, whether it be with a corporation or a consulting firm, is no different than lawyers or medical doctors who practice their profession. Engineering is a most necessary profession and the petroleum industry always has need for practicing engineers.

If you still want to be an executive after considering the transition which you must make to become an effective one, select your own path. But remember that adjustment is necessary, so consciously work toward making the necessary changes in your thinking. Realize that traditions, prejudices, attitudes, emotions, are real —whether or not they can be measured. The wheels of business turn on decision, so be prepared to decide—even on those problems which cannot be solved by engineering principles alone. Keep in mind that the timing of the action is sometimes as important as the correctness of the decision.

Industry is using more engineers in managerial positions than ever before. Through conscious effort, you can make the transition effectively. ★★★

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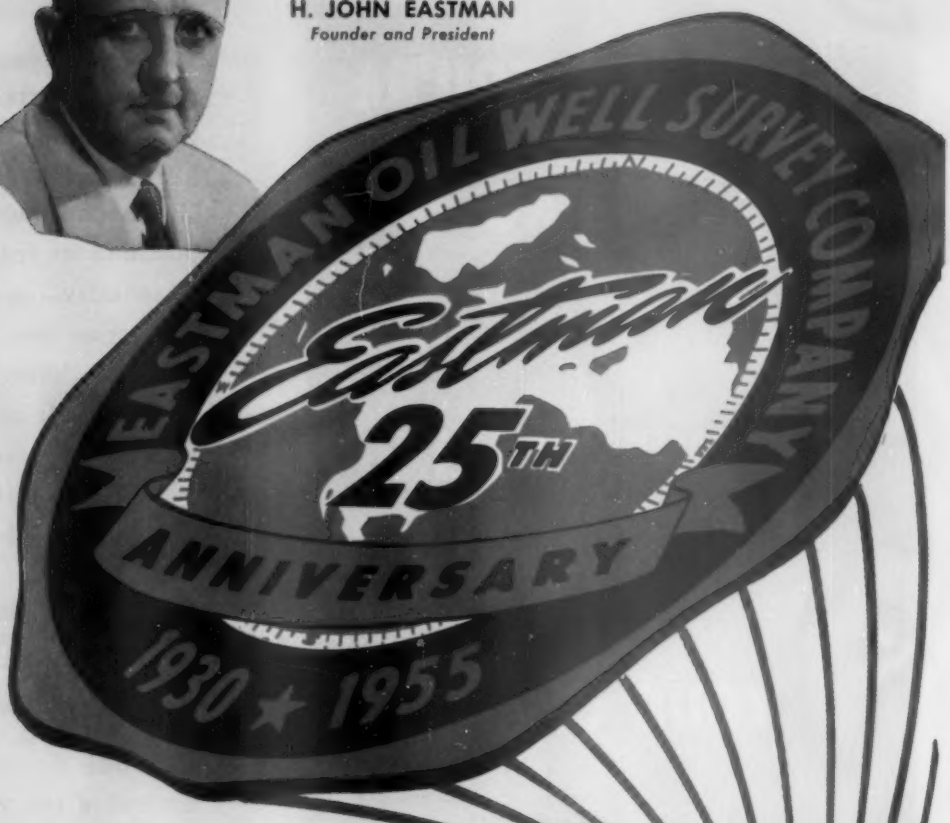

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21 Back-Off Operations Recover Entire Drilling String From 10,058'

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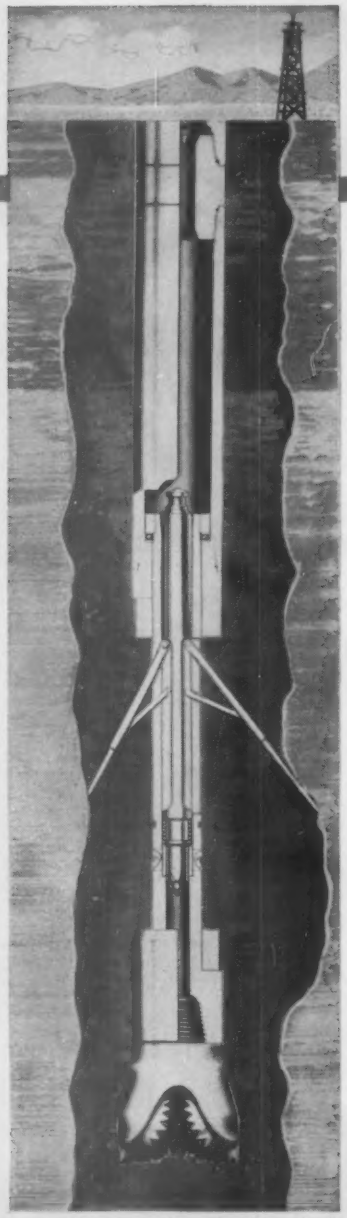

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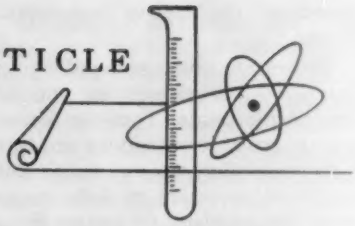

STUDIES of the MECHANISM of PARAFFIN DEPOSITION and ITS CONTROL

D. A. SHOCK
J. D. SUDBURY
J. J. CROCKETT

CONTINENTAL OIL CO.
PONCA CITY, OKLA.

Abstract

A review of the background literature on the paraffin deposition problem has shown: (1) it is a major production operational problem, (2) the problem apparently occurs in all crude oil types and areas of production, and (3) insufficient information is available to clearly delineate its occurrence. A number of experiments have been performed which show that there are numerous types of paraffin deposition. Several evaluation schemes have been devised, one of the most useful is the determination of viscosity at various temperatures. The viscosity-temperature curves of several types of crude oils are discussed with reference to the deposition problem. Solvent evaluation procedures have been proven useful in determining the response of a given paraffin to a proposed solvent treatment.

Introduction

When considering that wax or paraffin problems have been recognized as a major problem from the inception of oil production, it is slightly less than amazing that the literature contains only a handful of references in which the problem is surveyed. The latest thorough examination of the problem by Reistle[1] is now 20 years old. Brown[2] reported on the API survey in 1940, Wright[3] on Southeastern Ohio problems, and Sayre[4] on problems in the Bradford, Pa., field in 1951. These papers have discussed the various developments on the problem from an operational standpoint. There is no evidence in the literature that additional work is being done to define the conditions under which paraffin problems occur and examine critically the various means of alleviation.

During the past two years, the authors have gradually accumulated background on these aspects of the paraffin problem. The technology has advanced sufficiently that a new appraisal of the problem by the industry would yield profitable results. This paper is presented not so much as a completed investigation, but as a stimulus to encourage others to re-examine the problem. This presentation will cover our appraisal of the problem and several techniques we have found useful.

Geographical Occurrence

There is at present no data on which to draw any quantitative conclusions on the comparative severity of the problem by area or amount of production. The authors have endeavored to picture the problem on a qualitative basis only. Fig. 1 represents the location of reported field problems from our own organization and literature reported problems.[1,2,4,5,6,7,8,9,10,11,12] The crude oil classifications according to Smith[13] are shown along with the production by those crude oil areas. It is obvious that the problem is not limited to crude type or geographical area. Any study which will summarize the problem must examine a number of crude types and geographical locations. The complexity of the problem undoubtedly has been one of the major reasons that so little definitive work has been accomplished.

Fig. 1 — Location of paraffin problems and crude oil areas.

Contributing Factors

In the broadest sense a "paraffin" problem is any predominantly organic deposition which hampers the production of oil. This paper will consider all organic deposition as "paraffin" since there is no clearly defined difference between rod waxes, asphalts, and tar deposits. In order to obtain some knowledge of the nature and occurrence of these organic solids, it seems logical to ascertain: (1) their chemical constitution, (2) the solubility behavior in the physical and chemical environment between formation and atmospheric conditions, and (3) the rate and nature of deposition.

Chemical Constituents

By definition of the problem the organic compounds of the field termed "paraffin" must be those which are insoluble in the crude at the producing conditions. These will be the high molecular weight com-

[1]References given at end of paper.
Manuscript received in Petroleum Branch office on Sept. 3, 1954. Paper presented at Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954.

pounds of the various homologous series.

The specific composition of a given "paraffin" will depend on the nature of the crude. Thus the knowledge of crude compositions and their high molecular weight constituents would be necessary to fully understand the problem. Of course this is not probable in the near future; however, considerable progress is being made on identifying constituents by major classes. The classes of compounds recognized as possibly being in the deposits are: (1) aliphatic hydrocarbons—both straight and branch chains; (2) aromatic hydrocarbons; (3) naphthenes; and (4) resins and asphalts.

Fig. 2 lists two possible compounds of each type and shows the differences in structure, melting point, and boiling point of these compounds for which the data are available. Our terminology, while specific enough for lower molecular weight compounds, is inadequate in describing by class the higher molecular weight compounds. There is little reason to doubt that compounds of mixed saturated and unsaturated rings occur. Also, the length and number of side chains as well as degree of branching makes a marked difference in the solubility characteristics of both the aromatics and naphthenes. The resins and asphalts are undoubtedly our least easily classified compounds because of their complexity.[14]

Considerable effort, particularly from a refinery separation standpoint, has been put forth to identify and separate the high molecular weight paraffin waxes. The wax fraction contains largely the paraffins with smaller amounts of naphthenes and aromatics. Research on refined waxes has made a major contribution to an understanding of the behavior of these mixtures. The normal paraffins give rise to clearly defined needle crystals and are recognized as being the principle constituents of the crystalline waxes. The branch chains paraffins contribute the major portion to the microcrystalline waxes. The long straight chain naphthenic and aromatic types also contribute to the microcrystalline waxes and also have a marked effect on the type of crystal growth of macrocrystalline wax.

Clark[15] has shown that even the pure compounds give different crystal types depending on the conditions of crystallization. Other investigations have shown the generalizations stated above.[12,16,17,18,19,20,21] Reistle[1] and others have shown that paraffin or rod wax contains both types of crystal structure, and there is no data to justify any suggestion that one type predominates. It seems quite reasonable to expect that a paraffin deposition may contain a variation of asphaltic material and the macro and microcrystalline waxes.

As has been stated above, the structures of the resins and asphalts probably are the least well understood. It is easy to see that this should be the case by their nature. As described by Gruse and Stevens,[14] they make up the combinations of the other types, such as polymerization products, and oxygen and sulfur linked rings resulting from condensations of unsaturated oxygen and sulfur compounds. The identification of these compounds at present rests from an arbitrary solubility procedure. They are defined as the fraction insoluble in pentane under certain given standard conditions (ASTM D 893). The sub-group classification, according to Gruse and Stevens,[14] depends on their increasing insolubility in benzene and carbon disulfide. As a class they make a major contribution to the problem and are least understood. As will be pointed out later, there seems to be a definite relationship between the resistance to solvent treatment of the "paraffin" problem and the pentane insoluble content.

Solubility Behavior

Knowledge of composition and physical property changes of the gas and oil with changes in temperature and pressure from reservoir to stock tank has long been recognized as essential to production operation. It is obvious that the solids fraction of the oil (paraffin problem) could be investigated in a similar manner as gas and oil. Logically, for a true evaluation of this complex system, one should start with a sample under reservoir conditions and let it come to the equilibrium conditions equivalent to several points in the production system. This should establish the maximum paraffin problem to be expected at such conditions. This system apparently has not been reported and no data are available on deposition equilibrium values obtained by depositions from reservoir oil.

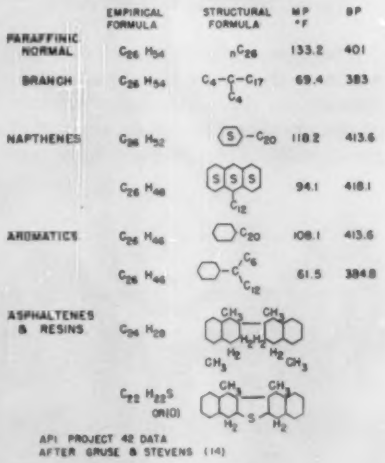

Fig. 2 — Possible compounds in paraffin deposition.

Considerable work exists on solubilities of paraffin waxes in hydrocarbon solvents.[16,22] Reistle[1] shows the relationship of the solubility of a paraffin deposition in three different gravity petroleum fractions at various temperatures. These data, shown in Fig. 3, are useful in generalizing on the magnitude of effect the variables of temperature and composition may have. The nature of crude and insoluble material would most certainly change the solubility values, thereby shifting the curves with each crude-solids system. Whether or not the general shape of the solubility curves is similar for various crude-solids systems has not been investigated. These solubilities show that the light ends contribute a major portion to the solubility of the wax and also the marked decrease in solubility with temperature.

The effect of dropping the temperature and losing light ends is very graphically demonstrated in Fig. 3. The difference in paraffin saturation as the crude changes is shown as the difference between A and B. Temperature change in the higher temperature region, near the melting point of the wax, is the major effect.

Schanen[22] states that the solubility of paraffin in liquid propane is about the same as decane. The methane solubility at atmospheric pressure is negligible although methane under pressure slightly increased the solubility. From the data available it would seem, however, that the loss of propanes and lower molecular weight hydrocarbons does not effect the solubility. Water apparently does not change the solubility of paraffin.[1] It has been noted in our laboratory that in some oils, particularly those of low API gravity, very viscous emulsions form and these are sometimes thought of as paraffin depositions. These cases are more allied to emulsion problems than deposition problems. The amount of water pres-

ent changes the viscosity, not necessarily the amount of deposition. The viscosity may become great enough to prohibit production and give the same effect as a deposition problem. This special type needs recognition, as the remedial measures applied to other "paraffin" problems are not generally applicable here.

Rate of Deposition

The rate of precipitation of solids from oils is usually considerably slower than the precipitation observed in water. The waxes tend to supersaturate easily and if equilibrium conditions change only gradually, relatively no deposition builds up in the flowing system. On the other hand the oil may be supersaturated and then subjected to a sudden change and very rapid deposition takes place.

As was pointed out in the previous paragraph the solubility of the paraffin waxes is very sensitive to temperature change. The factors which reduce oil temperature rapidly will cause the paraffin depositions to accumulate. Points of sudden gas liberation cool the oil and the minute gas bubbles provide nuclei for crystallization. Thus gas lift operations often provide excellent conditions for rapid paraffin depositions. Points of high heat loss are areas of paraffin accumulation. Thus, flow line and crude handling paraffin problems in cold weather are considerably greater than during the summer months. Insulation and use of low thermal conductivity materials (plastic lines) help reduce the problem.

Plastic surfaces also decrease points for crystal growth because they are usually highly polished. The smoothness factor has been demonstrated in that in using the same plastic in the same field installation a roughened surface accumulated paraffin deposits whereas the smooth did not. Sand and insoluble materials such as corrosion products or scale serve as nuclei for crystallizations to start. Keeping these at a minimum reduces possibility for crystal growth. It is commonly observed that depositions in the wells and lines decreases as water production becomes large. This is due undoubtedly to the greater specific heat of water and fluids from wells producing water always maintain a higher line temperature than those producing oil.

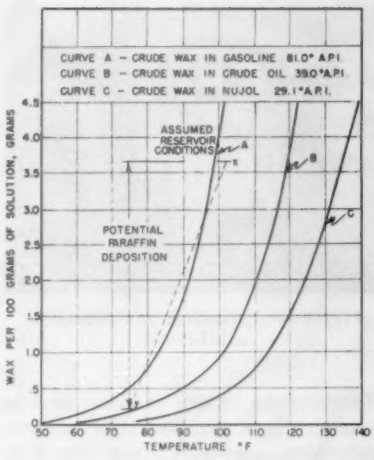
CURVE A – CRUDE WAX IN GASOLINE 81.0° A.P.I.
CURVE B – CRUDE WAX IN CRUDE OIL 39.0°A.P.I.
CURVE C – CRUDE WAX IN NUJOL 29.1°A.P.I.
ASSUMED RESERVOIR CONDITIONS
POTENTIAL PARAFFIN DEPOSITION
WAX PER 100 GRAMS OF SOLUTION, GRAMS
TEMPERATURE °F

Fig. 3 — Solubility of paraffin in crude oil—39° API; gasoline—81° API; and nujol—29.1° API.

Paraffin Control Methods

It is not the intent of this paper to critically review present paraffin removal practices. The papers of Reistle,[1] Brown[2] and Wright[3] give a good discussion of treatment types and their development during the past 30 years. A short review and literature survey has been included with the thought that such information should be recognized in a general discussion paper. The remedial measures fall into four general classes: operative, physical treatment, chemical treatment, and combinations.

Operative treatments have generally covered only reduction of loss of light ends and curtailing cooling by gas expansion. According to Brown[2] this method has received the least use.

Physical treatment is the largest of the methods used. Scraping devices[5,23,24,25,26,27] of various mechanical adaptations to fit particular services are widely used. Paraffin is sometimes removed from the sand face by shooting.[4] Heating devices probably are the widest used treatment.[7,28,29,30,31,32,33,34,35,36] This takes numerous forms in types of heat and mechanical application, such as steaming hot oil, electric heaters.

The chemical methods used to date have been through the use of solvents.[1,2,3,11,37] There has been a gradual increase in their use. The principal deterrent has been misapplication and a lack of appreciation of the limitations of a given solvent.

Methods of the combination class would include the chemical heat-solvent formulations where a portion of the chemical formulation reacts with the well fluids to produce heat and the use of soluble plugs which are both mechanical and solvent in function. Wright[3] concludes his paraffin survey to the effect that there is no single simple method for prevention or control of paraffin accumulation. The variety of treatment methods is evidence thereto.

Research Investigations

Numerous approaches have been made to evaluate the paraffin deposition problem. Our program resolved itself into two major phases: first, the examination and characterization of a number of paraffins from widely different geographic locations and crude types and second, a study of the crudes from these locations. Paraffin studies have been made on samples from each of the locations shown on the map in Fig. 1.

Examinations of Solid Paraffins

The methods used in investigating the paraffin deposits are as follows:

1. Visual Study—determine color and particle adherence qualities.
2. Microscopic study—determine the presence of water, sand and other inorganic particles and observe the nature of the wax.
3. Infra Red — determine semi-quantitative chemical composition.
4. X-ray Diffraction — determine the crystalline character of waxes and very poorly dispersed inorganic solids.
5. Pentane Insolubles—run by the standard ASTM D 893 Procedure. These are the resins and asphalts. They are divided into a benzene soluble and benzene insoluble fractions. The benzene insoluble fraction is defined as asphaltines.
6. Emission spectrographic analysis of the ash.
7. Solubility Tests — the paraffin was compared in solubility on a number of commercial solvents and in carbon disulfide.

Results on 12 different paraffin deposits are shown in Tables 1 and 2. Of all the results obtained, the solubility data were the most surprising. The solubilities are estimated by a modification of a field technique where the paraffin deposit is scraped evenly on a wire mesh and then dropped into solvent. The apparatus is shown in Fig. 4. A mechanical device lifts and lowers the screen at a uniform rate and an automatic

counter records the cycles. The effectiveness of the solvent is judged on the number of cycles to remove half of the paraffin from the screen. This is reduced to a number based on 100 by dividing the number of cycles into the number of cycles required to remove a heavy asphalt in CS_2 and multiplying by 100. This gives the solvent rating number which is shown in the table. Solvents A, B and C are commercially available solvents containing appreciable CS_2. Solvent D is principally aromatic in character and E is principally paraffinic with only a small trace of aromatic constituents. It is noteworthy that the ranking order changes very little between the "paraffins." Fig. 5 compares the solubility number of Solvent A with total pentane insoluble content of the "paraffins." There seems to be some correlation between the higher pentane insolubles and solvent response. The high pentane insolubles give poorer solubility numbers. There was no correlation between asphaltenes and solubility.

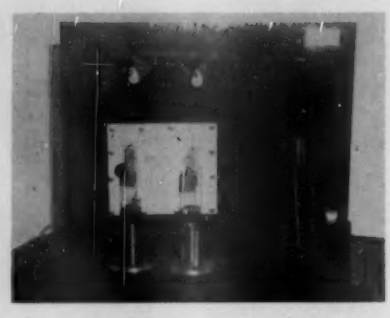

Fig. 4 — Apparatus for obtaining solubilities.

The benzene soluble fraction showed some correlation. The high benzene soluble fractions respond better to solvent treatment.

Examination of Crudes

Several methods of studying crudes have been tried to determine the nature and possible remedies for the "paraffin" problem. Of these, the viscosity-temperature curves have been of the greatest aid, although the others hold some promise. No totally satisfactory system has yet been evolved, however, there are three types of studies which have been of value: (1) viscosity-temperature curves, (2) chromatograms, and (3) the deposition rate studies.

Viscosity-Temperature Curves: The basis for this test was to find some means of evaluating the behavior of a given crude as it is cooled. The apparatus is shown schematically in Fig. 6. It consists of an insulated container in which a Brookfield Viscosimeter is inserted and provision is made for circulating the crude which can be heated or cooled through a fairly wide range (20° F to 130° F). The method of running the curve is to take the oil viscosity while cooling and then warm it up to the maximum temperature.

Fig. 7 shows several typical runs plotted on a semi-log scale. Curve A is the straight line plot obtained from a 200 pale oil. Curve B represents a South Texas high API gravity crude of high wax content. Deposition is very severe at the in-

TABLE 1 — PHYSICAL DESCRIPTION AND ASH ANALYSIS OF PARAFFIN

DISTRICT		East Kan.	Texas Panhandle	Wichita Falls Texas	South Okla.	Brownfield Texas	Ventura Calif.	Illinois Basin	New Mexico	Louisiana	North Okla.	Wyoming
FIELD		Solomon Pool	Carver Pool	Hundley	Sholem Alechem	Jenkins Devonian	San Miguelito	Griffin Field	Hardy Federal	Ville Platte	Ceres Pool	Sussex Pool
PHYSICAL DESCRIPTION												
Sand and Solids		Small Amount	Same Sand	Considerable	Small	Small	Small	Large	Small	Small	Small	Small
Water		Small Amount	Medium	Trace	Trace	Trace	Trace	Large	Small	Medium	Trace	Small
Color		Brown-Black	Gray-Black	Brown-Black	Dark Black	Dark Black	Brown-Black	Very Black	Brown-Black	Very Black	Gray Black	Very Black
PER CENT ASH		3.55	9.8	1.33	2.57	0.30	0.23	5.25	0.42	0.13	—	0.27
Spectrographic Analysis	Na	1.5	1.0	.07	1.1	.03	.06	.8	.13	.05	.006	.005
	K	.07	—	.04	—	—	—	—	.004	—	.03	.016
	Ca	.3	.2	—	.2	.02	.01	.3	—	—	.005	—
	Mg	.04	.09	.003	.03	.002	.01	.03	.008	—	+	.002
	Fe	.008	4.0	.13	+	.03	.002	1.3	.03	.01	.07	.01
	Si	.08	—	.4	.06	.05	.03	.1	.06	.01	.23	.016
	Al	—	—	.03	—	—	.006	.03	.003	.002	.05	—
	Pb	+	—	+	—	+	+	—	—	+	—	—
	Cu	—	—	+	—	+	+	+	—	—	—	—
	Mn	—	.02	+	—	+	—	+	+	+	—	—
	V	.01	—	—	.01	.002	.001	—	.001	—	—	+
	Ni	+	—	+	+	+	.001	+	+	+	—	+

TABLE 2 — SOLUBILITY OF PARAFFINS

DISTRICT	East Kan.	Texas Panhandle	Wichita Falls Texas	South Okla.	Brownfield Texas	Ventura Calif.	Illinois Basin	New Mexico	Louisiana	North Okla.	Wyoming
FIELD	Solomon Pool	Carver Pool	Hundley	Sholem Alechem	Jenkins Devonian	San Miguelito	Griffin Field	Hardy Federal	Ville Platte	Ceres Pool	Sussex Pool
SAMPLE NUMBER	P254	P203	P149	P247	P175	P97	P234	P157	P142	P96	P218
PENTANE INSOLUBLES	21.5	40.8	55.1	57.4	49.4	56.2	18.0	55.6	22.9	48.0	16.4
% Benzene Soluble	—	15.9	65.0	51.3	46.7	53.9	11.6	48.8	15.4	51.2	14.9
% Asphaltine	—	24.9	—	6.1	2.7	2.3	6.4	6.8	7.5	—	1.5
SOLUBILITY IN SOLVENTS*											
CS_2	69	18	17	50	2	6	60	22	26	21	60
Solvent A)	69	15	11	47	2	7	56	21	23	21	64
B)	53	17	14	50	2	8	60	22	24	22	69
C)	39	11	7	33	2	8	41	11	19	14	43
D	8	3	1	11	.04	2	15	2	3	3	17
E	13	10	3	16	2	3	18	5	4	5	17

$$\text{*Effectiveness Numbers} = \frac{\text{Dips to Clear Screen (Standard Paraffin)}}{\text{Dips to Clear Screen (Sample)}} \times 100$$

flection point. Curve C and Curve E are from the Carver area, Panhandle, Tex., and Tensleep production, Sussex field, Wyo., respectively, and demonstrate a curious phenomena. The arrows denote that the viscosities were taken on the cooling or heating cycle. With these crudes the viscosities are higher on the down, or cooling, cycle. As the crude is heated back up the viscosities are lower. It has been found that this is a reproducible phenomena. The prolonged heating tends to solubilize some of the solid material dispersed in the crude with a resultant decrease in viscosity. In Curve E solids tend to come out at the inflection point. Curve D is from Geneseo field, Kan. Here the heating and cooling cycle shows the effect of light ends being lost and viscosity increasing. This is the normal behavior for a crude.

Fig. 8 shows three more curves which illustrate another phenomena not hitherto appreciated. This crude is from the San Miguelito field, Calif., and has the property of forming very stable water in oil emulsions. Considerable lifting difficulty is caused by the formation of viscous accumulations. Curve A is the viscosity temperature curve of the dry crude. Solids accumulate at the inflection point but it remains pumpable. The introduction of 50 per cent lease water shifts the curve to B. This material is difficult to move at the lower temperatures. Curve C shows some beneficial effect of chemical treatment. The chemical is not a solvent and functions more as an *emulsion breaker*. It is believed that certain chemical treatments which are not solvents may be applicable to this type of problem.

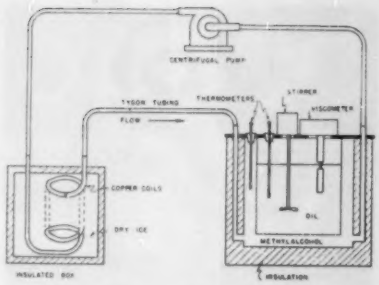

Fig. 6 — Viscosity temperature apparatus.

The viscosity curves have shown some marked differences in crudes. They have provided an insight as to when paraffin may be deposited. Samples of the solids deposited can be removed to be evaluated for solubility and analysis. It is evident that in certain crudes water plays an important part in the "paraffin" problem.

Chromatographic Characterization: The presence of heavy ends and possible "paraffin" problem has been indicated in a number of crudes by the chromatographic spot test. This is a development of the method reported by Schuldiner[27] who used it for identifying crudes for polution control. A drop of the crude is placed in the approximate center of a piece of white blotting paper about 2 by 3 in. in size. When the oil has reached its maximum size, 2 to 5 drops of non-fluorescing naphtha are placed in the center and allowed to spread. Most crudes develop zones or rings which are quite unique and very noticeable under ultra violet light.

Fig. 9 shows the chromatograms for several crudes. Crudes which have known "paraffin" problems show well developed rings close to the center. The high molecular weight insoluble compounds do not move away from the original drop. In the figure the rings are shown in the South Texas crude which gave the sharp viscosity-temperature break and in the Wyoming crudes. The heavy asphaltic crude from California which gives the viscosity increase with water is shown as are two crudes which give no paraffin problem. This technique may be useful, however, insufficient data are at hand to determine the quantitative value. For instance, there is no practical problem with the South Texas crude since the temperature of lines and tanks seldom, if ever, are cold enough for precipitation to take place. This same crude in Wyoming, on the other hand, could become quite a problem.

Deposition Rate Studies: Determination of actual rates of deposition of paraffin for a given crude would be the most helpful, however, to date we have not worked a scheme that is unquestionably successful.

Numerous schemes of cooling the crude while circulating through pipes and porous plugs were not very satisfactory. Two systems[39,40] have been reported that yield favorable results, depend on saturating the crude with paraffin from the field which had been scraped from the surface pipe. This high content paraffin solution in crude is run through a system where a portion of the piping is

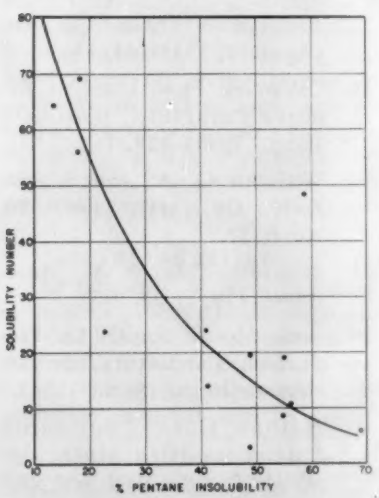

Fig. 5 — Solvent effectiveness vs pentane insolubility.

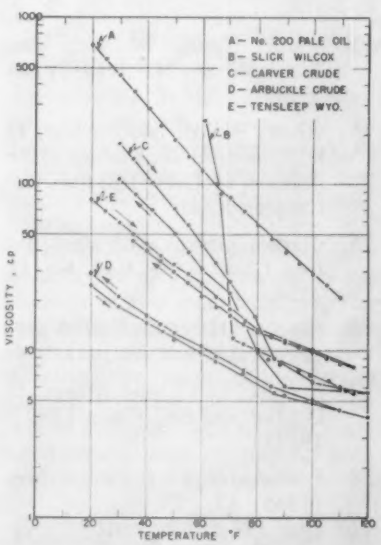

Fig. 7 — Viscosity vs temperature for various crudes.

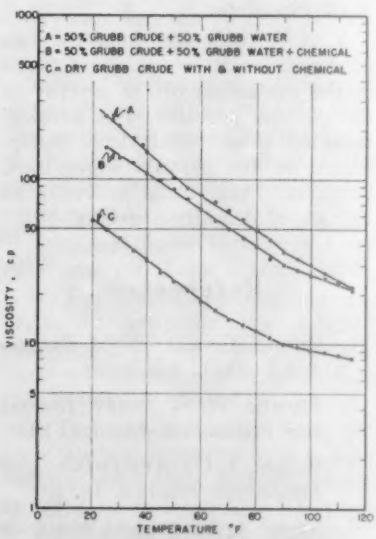
A = 50% GRUBB CRUDE + 50% GRUBB WATER
B = 50% GRUBB CRUDE + 50% GRUBB WATER + CHEMICAL
C = DRY GRUBB CRUDE WITH & WITHOUT CHEMICAL
VISCOSITY, cp
TEMPERATURE °F

Fig. 8 — Viscosity vs temperature for variation of water content.

immersed in a cooling bath. This scheme gives a measurable deposition rate and various alleviation methods can be evaluated in the laboratory if they are concerned with rate of deposition changes. It does not, however, give a measure of the amount of deposition to be expected from a given crude under field conditions. It is obvious that there is considerable need for the development of an evaluation scheme which more nearly approximates the severity of the problem.

Conclusions

1. The paraffin problem should be re-examined and better classified on an industry-wide basis. The problem seems to be distributed in all geographic locations and crude types.

2. The work demonstrated that there is a wide range of chemical compositions found in paraffin from the high molecular weight normal hydrocarbonates through the asphaltic resins. The solubility response to solvent treatment seems related to this composition. Thus the high asphaltine content paraffins all give poor solvent response to the commercial solvents now currently on the market.

3. There is a definite need for the development of systems which will evaluate and classify the potential paraffin forming tendency of a crude. The viscosity-temperature curves in a measure do this and show differences in the behavior of (1) normal paraffin deposits, (2) crudes containing colloidal asphaltines, and (3) crudes forming very viscous water in oil emulsions.

4. It is recognized that the rate of deposition is an important factor in the evaluation of the severity of the paraffin problem. The development of agents which delay precipitation of the paraffin seems quite probable. These could be evaluated by rate of deposition studies.

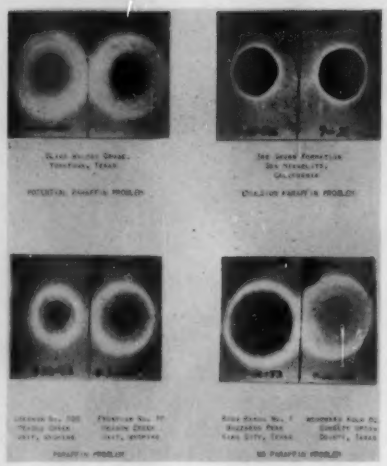

Fig. 9 — Chromatograms for several crudes.

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FIELD WELDING on OILFIELD TUBULAR GOODS

J. N. BIRON
B. G. FRAZIER
GULF OIL CORP.
HOUSTON, TEX.

Abstract

Examination of several typical samples of field welding of scratcher and centralizer lugs revealed that the quality of welds was inconsistent and generally poor. Damage to the casing could usually be expected. The holding capacity of the welded lugs and of the equipment itself against the lugs was found to be of a very low order.

A non-technical summary of the effects of welding on oilfield tubular goods is presented. It is shown that the tubular goods steels require a stricter welding procedure for quality welds than steels in general industrial use. A study of this will give the busy supervisor a fair appreciation of the problem of joining metals by arc welding.

Having established the effects of welding, the control of these effects as they concern field application is considered. Welding at the rig site is classed into five categories, namely, (1) welding scratcher and centralizer lugs, (2) welding collars, floating equipment, (3) welding casing hangers, (4) orange peeling of conductor to surface pipe, and finally, (5) welding of casing and tubing as piping. The peculiarities of each category are discussed and recommendations made when applicable.

Introduction

The frequency of holes in casing set in wells gave rise to the suspicion that the failures were related to the field arc welding done on the casing. The welding of scratcher and centralizer stops or lugs on casing is a common practice. It was decided to determine the quality of field welding of these appurtenances to the casing and to evaluate its effect on the wall body. Several typical samples of field welding of scratcher and centralizer stops were examined and tested.

After determining the quality of the welding being done in the field, the next step was to investigate methods of improvement. A review of published literature and consultation with welding engineers provided welding and metallurgical information. Since current laboratory knowledge was not being put to use, translation of the laboratory knowledge into a simple explanation for rig operations was needed. A brief and non-technical discussion of welding on high carbon-alloys steels was prepared to foster a better understanding of the problem by those supervising field welding operations.

Typical Examples of Field Welding on Oilfield Casing

A joint of 5½-in casing having lugs and attachments was selected from each of three separate wells prior to running casing. This represented the work of three different contract welders.

The information that follows, particularly the photographs, shows the products of two manufacturers. The data have been coded so that the identity of any product with respect to rating or point of failure is masked. It is the intent of this report to evaluate "field welding," not the products involved, and no such inference should be made.

Evaluation of the Welding of Scratcher Lugs

The general testing procedure was to force the band (body) of the scratcher against the lugs and record the force required for "pull off" of the lugs, or failure of the band (riding over the lugs). The remaining lugs were pulled off individually and the force recorded to the nearest 100 lb.

On six pull tests of scratchers against the lugs, the scratcher band failed first in five instances, i.e. rode over the lugs (see Table 1). Data in Table 1 is significant in that it established some rating on what the scratcher bands will withstand under this method of installation. Figs. 1 and 2 show the condition of two of the scratchers that were pulled over the lugs.

TABLE 1 — FORCE TO PULL SCRATCHER OVER LUGS
(Only Scratcher Band Failure Considered)

Field Welder "X," 5½ in J-55 Casing	
Scratcher Manufacturer A	14,700 lbs
Field Welder "Y," 5½ in N-80 Casing	
Scratcher Manufacturer B	9,900 lbs
Scratcher Manufacturer B	11,900 lbs
Field Welder "Z," 5½ in N-80 Casing	
Scratcher Manufacturer A	11,800 lbs
Scratcher Manufacturer A	13,000 lbs
Average =	12,260 lbs

Table 2 indicates the forces required to "pull off" each of the lugs. The entry "low impact" is the result of the cylinder sleeve striking the second lug after pulling off the lug under test.

Some significant facts of the results shown in Table 2 are:

1. The inconsistent holding capacity of any one lug, (spread data) among the three welders. Each welder had one or more lugs that practically fell off.

2. The over-all average "pull off" force per lug, 10,463 lb, is very low, and the low impact failures are not included in this average. Referring to Table 1, the average "pull over" force for the scratcher band against three lugs was 12,260 lb.

Paper presented at Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954. Original manuscript received in Petroleum Branch office Aug. 2, 1954; revised manuscript for publication received on Aug. 4, 1955.

Fig. 1 — Sample scratcher body after pulling over welded lug stops.

Fig. 2 — Sample scratcher body after pulling over welded lug stops.

Fig. 3 — Sample of centralizer weld after pull failure.

Fig. 4 — Location of centralizer weld that worked out while in transit from well location to testing rack.

3. All of the lugs welded on the N-80 pipe pulled base metal out of the pipe along the hard zone and left gaps in the pipe wall up to a maximum depth of 0.138 in. in specimen B-4. Some of the lugs on the J-55 pipe pulled base metal out of the pipe also.

Test of Field Welding of Centralizer Lugs

There were four centralizer pull tests made, two simulating going in the hole and two simulating an upstroke. Tables 3 and 4 give the results.

TABLE 3 — FORCE TO PULL OFF CENTRALIZER (Going in Hole)

Manufacturer	
C	Field Welder "Y," 5½ in 20 lb N-80 pulled off three tack welds with 35,500 lbs.
D	Field Welder "Z," 5½ in 20 lb N-80 broke weld with 4,200 lbs.

TABLE 4 — FORCE TO PULL CENTRALIZER OVER "GAGE" WELDS OR TO BREAK WELD (On the Upstroke)

Manufacturer	
C	Field Welder "Y," 5½ in 20 lb N-80 pulled off three tack welds with 28,300 lbs.*
D	Field Welder "Z," 5½ in 20 lb N-80 broke weld with 11,300 lbs.

*Band crawled completely over three stops at 28,300 lb. Specimen B-4 shows one of these stop welds.

The inconsistency of the capacity of the weld is again significant, ranging from 4,200 lb to 35,500 lb, a spread of 31,300 lb. Figs. 3 and 4 show the centralizer tests. Fig. 4 shows good evidence of the extremely hard heat effected area. The lug actually worked out of the pipe while is transit from the well to the testing rack.

Laboratory Analysis

Strip specimens were obtained from the tests and prepared for laboratory analysis. Each specimen (sectioned through the weld area) was polished and etched to bring out the effects of the welding operation. The specimens are described as follows:

Specimen B-2, Fig. 5, is one of two scratcher lugs that was in contact with the drive sleeve simultaneously; both pulled out at 15,300 lb, or 7,650 lb per lug. Note the irregular heat affected line denoting variable heat input during welding (starting and stopping point of the weld). The maximum depth of gap in this specimen is 0.130 in. A crack is evident in the brittle, heat-affected area to the left of the remaining weld metal. A hardness profile across the weld metal section is shown. Note again the great difference in hardness at the fusion line and throughout the heat affected zone as compared to the unaffected casing. The chemistry of this specimen was found to be: carbon .43 per cent; manganese 1.43 per cent molybdenum .18 per cent.

Specimen B-4, Fig. 6, was a one-stop weld of a three-stop weld band to limit centralizer travel on the upstroke. The centralizer band crawled over the three welded stops at 28,300 lb. The lugs were sheared (after the centralizer band had completely crawled over the lugs) by the close fitting drive sleeve. The gap to the right of the weld metal in Specimen B-4 was 0.138 in deep at the deepest part along the etched surface. This gap is the start of the weld where the welder first struck his arc. The heat affected zone appears to be fairly uniform and deep, as compared to the other specimens; however, the hardness profile shows the high hardness at the fusion line and throughout the heat affected zone. This weld would most probably have pulled out and removed a portion of the original base metal had it been subjected to loading transverse to the weld bead. The high hardness at the fusion line and throughout the heat affected area is not favorable when compared to the hardness of the unaffected casing. The chemistry of this specimen was found to be: carbon .41 per cent; manganese 1.44 per cent; molybdenum .19 per cent.

Specimen C-2 in Fig. 7 is one of two lugs that pulled out simultaneously at 11,800 lb, or 5,900 lb per lug. Two large cracks can be seen on the ends of the weld, which run parallel to the weld. Several cracks can also be seen running across or

TABLE 2 — FORCE REQUIRED TO PULL OFF LUGS (Lugs Welded as Scratcher Stops)

Field Welder "X," 5½" J-55 Casing		Field Welder "Y," 5½" N-80 Casing		Field Welder "Z," 5½" N-80 Casing	
Sample No.	Single Lug Pull Offs	Sample No.	Single Lug Pull Offs	Sample No.	Single Lug Pull Offs
1	8500 lbs			1	7,400 lbs
2	9900 lbs			2	13,300 lbs
3	*Low Impact	1	18,200 lbs	3	7,100 lbs
4	*Low Impact	2	17,000 lbs	4	16,900 lbs
5	18,200 lbs	3	*Fell Off	5	12,400 lbs
6	11,900 lbs	4	24,700 lbs	6	8,800 lbs
7	14,200 lbs	5	9,900 lbs	7	*Low Impact
Average	12,540 lbs	Average	17,450 lbs	8	14,700 lbs
				9	7,100 lbs
				10	18,300 lbs
				Average	11,777 lbs

Over-All Average 10,463 lbs.
*Not weighted in averages

perpendicular to the weld. The chemistry of this specimen was found to be: carbon .43 per cent; manganese 1.01 per cent; molybdenum .14 per cent. The deepest depth of pit is 0.081 in. Note again the irregular heat-affected zone.

Specimen C-6 in Fig. 8 is a single lug test that pulled off at 7,100 lb. Several perpendicular cracks in this specimen are probably the result of grinding and polishing prior to etching. Greatest depth of pit is 0.116 in. The greater depth of heat penetration in the right side denotes the starting point of the weld.

Discussion of the Effects of Welding

Arc welding on the type casings under discussion produces profound effects in the weld area. Numerous investigators in the metallurgical and welding fields have contributed valuable information to industry concerning the effects of welding on metal and oil field casing.

The cooling time or the rate of cooling of a weld after the generation of heat is stopped is of paramount importance, for it determines the structure of the steel in the weld area. Casing steels exhibit a structure of pearlite and ferrite. When a steel is allowed to cool at different rates through the critical range, different structures will be obtained.

One such structure, which is obtained by allowing a steel to cool rapidly, is termed martensite. It is a very fine, hard, brittle structure, the hardness being dependent upon the carbon content of the steel. This structure is highly unfavorable in a weld.

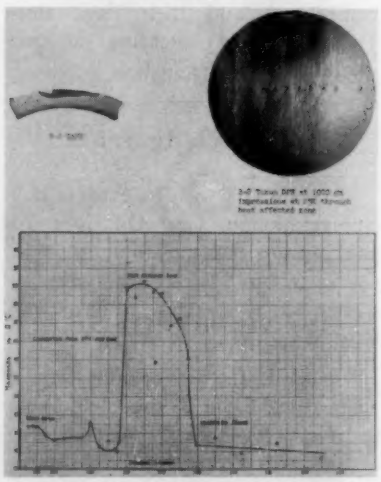

Fig. 5 — One of two scratcher lugs that was in contact with the drive sleeve simultaneously. Both pulled out at 15,300 lb, or 7,650 lb per lug.

Cooling a steel less rapidly permits the formation of pearlitic structures which are softer and more ductile than the martensite, making them more favorable.

When a steel is allowed to cool very slowly, the resulting structure is very soft. The proper rate of cooling through the critical range to form a favorable structure varies with the various types of steel. The desired rate of cooling is one which is slow enough to avoid the formation of martensite and to give a favorable pearlitic structure. Casing with high carbon and alloy contents is more difficult to weld than low carbon casing and usually requires special practices to obtain sound welds.

The greater portion of casing strings being run today are of the threaded connection type. However, some years ago, considerable attention was given to finding suitable methods for welding oil well casing in the hole in lieu of the threaded connection joints. L. R. Hodell[1] dealt ably with this problem studying a carbon content between the ranges of .20 per cent to .30 per cent. Hodell's investigation revealed that some types of casing were not suitable for field welding, and it is of interest to note that the carbon content of these casings was above .30 per cent. The problem, while not related to welding these casings in the hole, does involve welding in some manner on these higher carbon casings.

Perhaps one of the most detrimental effects noted to date is the welding of small lugs or metal stops

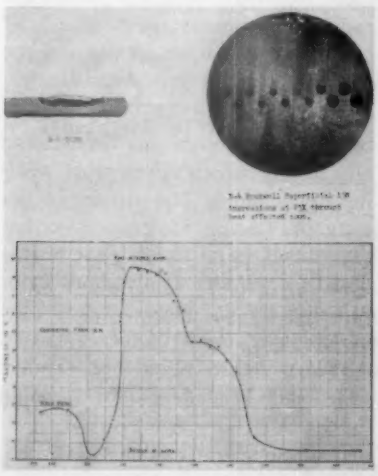

Fig. 6 — One-stop weld of a three-stop weld band to limit centralizer travel on the upstroke. Centralizer band crawled over the three welded stops at 28,300 lb.

to casing for the purpose of spacing scratchers and centralizers. Some typical results of this practice have been presented. From the hardness profile across the weld zone in Specimen B-2 and B-4, it is obvious that the weld cooled too fast. The welding of a small lug to a relatively thick walled section produces an effort known as the mass quench, that is the heat being dissipated throughout the large mass of metal surrounding the small weld. The effect of this mass quench on the hardness of the heat affected area may be seen if the maximum hardness readings of the heat affected zone of Specimen B-2 and B-4 are compared to the maximum quench hardness possible, Fig. 9, for their respective carbon content. For all practical purposes, the maximum hardness in the heat affected area in both cases is the maximum quench hardness possible for the respective carbon content of those steels.

Most of the specimens showed evidence of underbead cracking. This is attributed to the inability of the weld metal to undergo the stresses imposed upon it during cooling, the weld metal being less ductile than the cooler base metal. From Fig. 9, it can be seen that the maximum hardness after a rapid quench is dependent upon the carbon content alone. Alloying does not tend to increase the maximum hardness; however, the addition of alloys permits a steel to be hardened deeper and easier than steel with straight carbon content. Preheat is necessary prior to welding to slow down the cooling rate.

Tack welding of floating equipment and collars is a common practice usually performed without the use of any preheat or other special practices. The function of this operation on the floating equipment and the two or three bottom joints is usually said to aid in preventing the

Fig. 7 — One of the two lugs that pulled out simultaneously at 11,800 lb or 5,900 lb per lug.

Fig. 8 — Single lug test that pulled off at 7,100 lb.

[1]References given at end of paper.

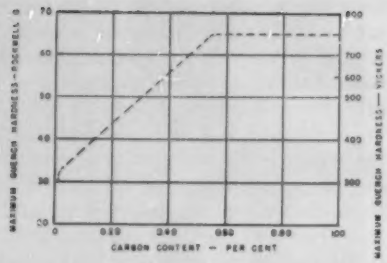

Fig. 9 — Influence of carbon content on maximum quench hardness.[2]

pipe from backing off while drilling out cement. Several instances have been noted where the bottom joints have been disconnected from the casing string even though tack welding practices were used. The general effects of welding a small single bead are similar to those produced in the welding of lugs or stops to the casing body.

Many weldability tests have been conducted on casing couplings to determine a proper cooling time after welding. Hardness values in the heat affected area decreased as cooling time increased. Only the welds that were preheated to 700° F and allowed to cool five to six minutes showed a favorable microstructure. Any welding procedure for this application should specify that at least two beads or passes be used. Weldability tests of couplings to casing using two beads and no preheat, but allowed to cool slightly over five minutes, did not contain any hard spots; however, the heat affected zone was very narrow and broke off suddenly under test. Fig. 10 shows two specimens from a series of such tests conducted by Reed Roller Bit. This is an excellent visual portrayal of the effects that the rate of cooling has on the heat effect zone.

A problem worthy of mention concerns the welding of slip test weld casing hangers. Prior welding difficulties in this operation have caused considerable concern. This application varies somewhat from a regular welding operation in that only a pressure seal is needed, since the casing tensile load is carried on the slips. Resistance to burst may be or may not be of concern, depending upon the type of hanger design. The solution to this problem has been aided by various wellhead manufacturers who have established welding guides for use with their product. Most of the welding problems have been eliminated when this guide has been followed diligently. Basically, the steps cover proper preheating practices, a staggering sequence of the weld beads to avoid concentrated stresses, using as low a heat input as possible, and warming the weld after welding to allow slow cooling. These steps have been found to be mandatory when making casing hanger welds on casing of N-80 grade and higher.

The task of orange peeling and welding the conductor pipe to the surface casing or to the surface casing head housing is a practice usually performed soon after the surface pipe has been set. There are arguments against both; however, the authors are not aware of any serious trouble resulting from either method. The thickness of the materials being welded and the fact that normally two or more passes are run probably account for a reasonable satisfactory welding job. Lack of any difficulties resulting from orange peeling has precluded any detailed examination of such an application. The use of preheat on the surface casing would no doubt aid in obtaining a better weld, however, this would be a difficult task. The authors believe that preheating a casing head housing in the field would be an impractical task.

Oftentimes around the rig or field, old tubing, casing, or drill pipe is used for flow lines or piping. Any recommended welding procedure concerning tubular goods would, of course, depend upon its use and the procedure would vary accordingly.

The American Welding Society has set up requirements for welding and testing which cover most welding applications. The American Society of Testing Materials also has established tests and procedures based on welding applications. Prior to using tubular goods as line pipe or piping, a review of the AWS and ASTM standards should prove most beneficial. Procedures for welding the material concerned in any particular application can be established. Tests for qualifying welders for that procedure can be provided. It would indeed be a forward step if bids soliciting welding contract work would contain a welding procedure and qualifying test requirements.

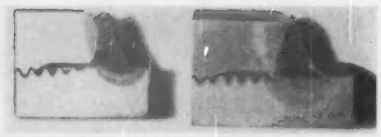

Fig. 10 — Two specimens from a series of weldability tests of couplings to casings conducted by Reed Roller Bit.

Conclusions

1. The welding operations discussed in this report involve metals of higher carbon and alloy content than those used in most conventional welding applications. As the carbon and alloy content increase, the welding operation becomes more difficult.

2. Welding on oil field tubular goods introduces drastic changes in the heat affected area. The quality of the finished weld is probably some 90 per cent dependent upon the welding technique.

3. Poor quality in field welding is usually due to failure to observe rules of good practice for the material in question.

4. A set of welding procedures should be adopted that embody the operations normally encountered in field operations.

5. Better methods than welding are needed for the following applications: (a) securing the lower joints and float equipment of casing strings, (b) attaching scratchers and centralizers and their limit stops (lugs), and (c) securing the conductor pipe to the surface pipe.

Acknowledgments

The authors wish to express their appreciation to Gulf Oil Corp. for making this paper possible.

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FEATURE ARTICLE

THEORETICAL and PRACTICAL ASPECTS of FREE PISTON OPERATION

J. M. LEBEAUX
ASSOCIATE MEMBER AIME
L. F. SUDDUTH

STANOLIND OIL AND GAS CO.
MIDLAND, TEX.

Abstract

Theory of operation of the free piston as well as practical limits of the device in prolonging flowing life of wells producing from volumetric type reservoirs are discussed. Reservoir behavior and the gas expansion work formalae are used to exhibit utility of free piston in prolonging natural flowing life. Examples are exhibited to show actual performance of the tool in West Texas. Investment and operating costs of the free piston are compared with those required for other artificial lift methods. A nomograph which may be used in determining adaptability of the tool is exhibited. Use of the free piston in intermittent gas lift operations is briefly mentioned.

Introduction

The basic idea of interposing in the tubing of a producing well of a solid interface, between gas and liquid phases of the produced fluid, to increase the efficiency of the lift is not new. In the original plunger lift the interface used was a solid critical diameter piston. The increase of efficiency of lift was obtained by better utilization of the energy of the compressed gas, either of the formation gas or of compressed gas supplied to the well from an outside source. Reduction to a minimum of the channeling of gas through the liquid phase and the falling back of the oil and water to be produced resulted in better utilization of the energy. This type of installation required a perfectly cylindrical and uniform diameter tubing to permit the travel of the tool.

Several years ago a free piston was developed which incorporated an expanding rubber element for sealing against the tubing wall and was therefore applicable in any conventional tubing string. Fig. 1 shows the piston.

The piston is manufactured in two types: Type 1, which is designed for installations using an outside source of gas; and Type 2, which is designed for those installations which use the well's own energy as a driving mechanism. This paper will consider only the latter type of free piston which has had considerable success in operations in West Texas, with the performance of the Type 1 only very briefly mentioned later in the text.

Operation of Free Piston

The operation of the free piston has been described in the literature.[1] Fig. 2 shows the sequence in the operation of the free piston.

The time-cycle rather than a pressure control cycle has proved most effective in that better control of the flow cycle can be achieved with a time controller in the West Texas wells. The time-cycle control can be set to close immediately after surfacing of the tool and is not effected by small fluctuations in well characteristics.

Experience indicates that each well must be considered individually with tests conducted to establish the optimum cycle of operation. Flow periods varying from 22 minutes per hour to 30 minutes every three hours have been observed. In order to secure maximum production, considerable experimenting with various flow cycles is often necessary. This fact must be impressed upon operating personnel. Otherwise, the tool may be condemned prematurely whereas satisfactory operation could be eventually obtained through experimentation.

Application

As mentioned previously, the Type 2 free piston is designed for those installations which require no outside source of gas. It has been found that the following type wells producing from volumetric type reservoirs are ideally adapted to the use of this tool.

A. Wells which tend to die during their flowing life, necessitating swabbing or other methods of lift to reestablish flow.

B. Wells which require agitation to bring about flow.

C. Intermittent flow wells which tend to load up.

An example of Type A occurred in a well in the Fullerton Clearfork field. Prior to the installation of the free piston, the well tended to load up and die, requiring frequent swabbing. After installation of the piston in Sept., 1952, the well has produced an average of 34 BOPD.

Paper presented at Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954. Original manuscript received in Petroleum Branch office on Aug. 13, 1954. Revised manuscript received on Aug. 15, 1955.

[1]References given at end of paper.

A second well in the Fullerton field, which can be classified as Type B, had been on the pump for approximately four years before installation of the free piston. The well required periodic pumping to agitate the well fluid and maintain natural flow. A free piston was installed Feb. 1, 1953, and the pumping unit transferred to another well on March 25, 1953. The production was 27 BOPD and 2 BWPD, both pumping and using the free piston as a means of artificial lift.

An example of Type C is a well in the Keystone-Devonian field which exhibited a tendency to die unless produced at rates higher than the daily allowable. Swabbing costs were approximately $200 per month. A piston was installed during March, 1954, and the calendar day allowable of 56 BOPD has been obtained to date without failure of the tool. No swabbing jobs have been necessary since the piston was placed in operation.

TABLE 1 — PERFORMANCE SUMMARY OF FREE PISTON IN WEST TEXAS OPERATIONS.

Well No.	Setting Depth Bottom Stop	Producing Formation	Production Before BOPD	BWPD	GOR	Production After BOPD	BWPD	GOR	Remarks
1	7,000	Clearfork	28	0	7,719	37	0	5,660	
2	6,700	Clearfork	28	1	4,640	28	1	1,670	Well on pump for four years previously.
3	6,800	Clearfork	28	0	3,624	30	0	2,969	
4	8,020	Devonian	65	0	2,767	56	0	3,310	Well required $200/mo swabbing before piston removed by free piston.
5	8,032	Devonian	32	0	6,250	65	0	1,860	High GOR penalty.
6	8,100	Devonian	24	0	1,750	20	0	1,850	Well on pump before piston installed.
7	6,299	Clearfork	17	0	4,639	34	0	3,362	Well died, piston installed 8-13-53.
8	5,057	Clearfork	27	0	2,745	17	17	1,685	Producing under packer.
9	4,157	San Andres	5	0	28,469	22	0	2,364	
10	4,161	San Andres	21	1	4,529	17	0	3,794	Well on pump before piston installed.
11	7,806	Spraberry	65	5	1,250	0	0	650	Beam equipment installed.

Table 1 lists some of the successful applications in West Texas and all have been in volumetric or solution gas type fields. Well No. 1 is an example of Type A; Well No. 2, Type B; and Well No. 4, Type C.

The only unsuccessful application to date is Well No. 11 and serves to aid in establishing limitations of the device in assisting natural flow. The test was started in Jan., 1953, at which time the well was flowing but swabbing was occasionally required to maintain the flowing production. The well had a gas-oil ratio of 1,250 cu ft/bbl at the outset, and the piston functioned somewhat erratically from the start of the trial installation. The test was suspended during the Spraberry shut-in period and tests were resumed after the field was returned to production. The gas-oil ratio had declined to approximately 500 cu ft/bbl and the piston did not function. The well is now pumping with beam type pumping equipment.

That the tool is particularly adapted to wells producing from volumetric type reservoirs is effectively illustrated by Figs. 3, 4 and 5. Fig. 4 converts the volume-pressure relationship to an energy function from the work formula plotted in Fig. 5. It emphasizes that during the phase of life of a volumetric reservoir when the bottomhole pressure becomes low, a very large amount of energy is available to maintain the flow of the well, because of increase in volumes of produced gas. Calculation of the values involved in the flow system by Bernoulli's thermodynamic equation becomes extremely complex in the multicomponent, two-phase flow system in a producing oil well. However, all factors such as friction losses, heat losses, and others may be conveniently reduced by an empirical overall efficiency factor which may be applied to the calculated gas expansion energy.

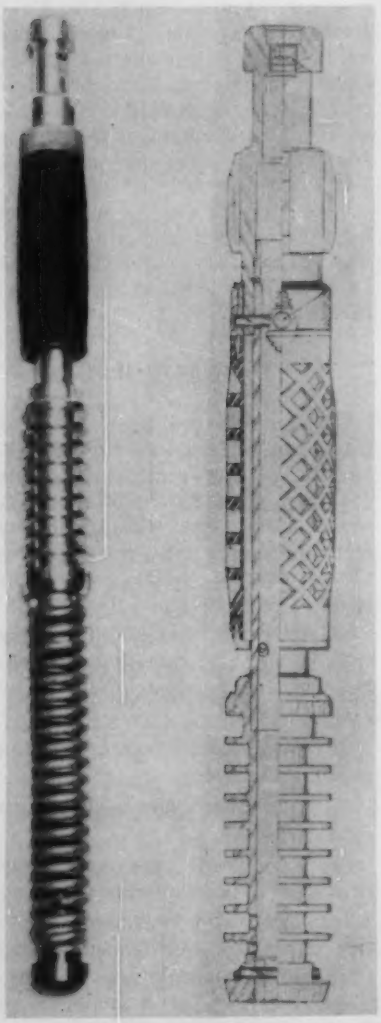

Fig. 1 — View of free piston and half-section drawing.

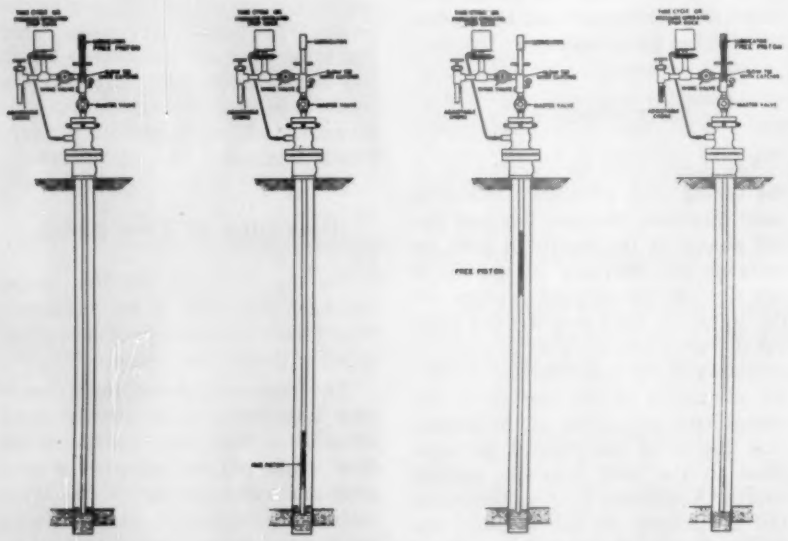

Fig. 2 — Sequence in operation of free piston: (1) piston is introduced to the well, packing elements in collapsed position; flow line valve is closed; (2) piston falls to lower stop, fluid builds up above piston; (3) flow line valve opens and piston starts to surface, packing expanded; and (4) piston passes into lubricator assembly, fluid passes down flow line to separator and cycle is repeated.

The lift efficiency of the work system in a flowing well is calculated by determining the input energy by expansion of formation gas between the limits of the flowing bottomhole well pressure and the flowing wellhead pressure with the output work being the hydraulic horsepower necessary to elevate the liquid from the reservoir datum to the surface. A few of these efficiency values calculated from flowing wells are plotted in Fig. 6 as a function of the gas-oil ratio. It will be noted that for the wells on which data was obtained the efficiency values fell between 10 per cent to 30 per cent. With these observed efficiencies it then becomes quite easy to develop the work requirements for maintaining flowing production. The efficiency of the flow system is improved by the free piston in that slippage of gas through produced fluid is reduced to a minimum. The work necessary to elevate a barrel of fluid even at low efficiencies is quite small compared to the energy per barrel available from the expanded gas (Fig. 4).

Application of the free piston may be determined by the nomograph presented as Fig. 7. The nomograph is derived from work and energy calculations assuming a fluid specific gravity of unity and an overall system efficiency of 33 per cent. The assumed efficiency compares favorably with the minimum value shown in Table 2. Flowing bottomhole and wellhead pressure plus depth to the working fluid level are used to determine the minimum producing gas-oil ratios necessary for operation of the piston. If the producing gas-oil ratio exceeds the minimum, there is an excellent prospect for sustaining flowing production with the free piston. The curves have proved realistic in determining applicability in numerous wells. Additional experience in use of the free piston will possibly lead to minor corrections in the efficiency factor upon which the curve is based.

Gas Requirements

In producing a well with the free piston, in most instances the casing annulus acts as a storage chamber for gas under pressure. Energy is stored in the form of gas under pressure and the build-up is over a period of time. Delivery of energy is rapid and in many respects is identical to stopcock flow of weak wells. As pointed out previously, the lift work is done by the gas expanding from a high to a low pressure. The inspection of charts recording the tubing and casing pressures reveals an almost instantaneous drawdown to the lowest tubing pressure recorded followed by build-up until the fluid reaches the surface. This is followed by other small fluctuations for any additional slugs of fluid. Casing pressure then drops off until the flow line valve closes. These data permit calculation of the gas volume withdrawn from the annulus during a flow cycle. In view of the sudden drawdown, it is not believed justified to assume an expansion to the lowest tubing pressure observed. Instead, the average drawdown pressure is considered more nearly accurate for calculations.

Casing and tubing pressure behaviors during the flow cycle are illustrated in Fig. 8. A correction is made to compensate for the pressure head of the compressed gas column, inasmuch as the actual work is done by the casing gas expanding as it enters the tubing.

It is also assumed that all the gas drawn from the casing during the cycle is utilized in lifting the free piston from its setting depth to the surface. In order to obtain the volume of gas used, the maximum and minimum casing pressure during the cycle are observed. The total annular volume is known, and it is relatively simple to calculate the volume of gas which must be removed from the annulus during each cycle to bring about the observed pressure change. In making these calculations, it is assumed that the casing gas behaves as an ideal gas, compressibility and other factors being neglected. It is believed that the values given by this method of calculation are of suf-

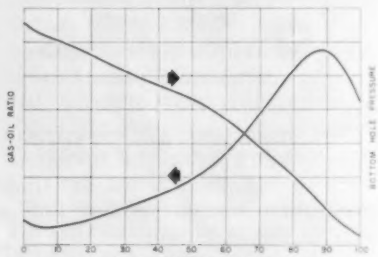

Fig. 3 — Bottomhole pressure and gas-oil ratio behavior of a typical volumetric type reservoir.

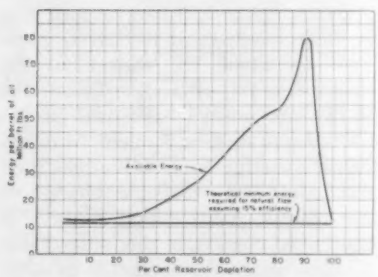

Fig. 4 — Available energy per barrel of oil at stages of depletion for a volumetric type reservoir.

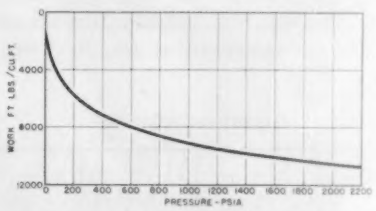

Fig. 5 — Plot of $W = RT \ln \frac{P_1}{P_2}$, gas expansion work formula by which GOR-pressure function is converted to available work.

TABLE 2 — THEORETICAL AND ACTUAL GAS LIFT REQUIREMENTS BASED ON DELIVERY FROM THE CASING AND ANNULUS ON TWO WELLS.

Flow Interval	Casing Pressure	Tubing Pressure	BOPD	Choke	Lift Gas Cu Ft/Bbl, per 1,000 Ft Theoretical	Lift Gas Cu Ft/Bbl, per 1,000 Ft Actual	Per cent Efficiency
Well No. 1							
14½ hrs every 24 hrs	950-660	950-375	29	14	238	75	*
6 hrs every 12 hrs	920-660	920-380	27	15	243	129	*
30 min every 4 hrs	885-645	840-210	25	24	188	386	49
30 min every 2 hrs	830-720	800-300	29	18	225	300	75
20 min every 1 hr	640-530	600-180	40	24	196	457	43
22 min every 1 hr	600-490	560-160	38	24	194	476	41
24 min every 1 hr	580-470	540-210	37	24	219	491	45
Well No. 2							
30 min every 2½ hrs	475-300	290-20	28	Open	130	404	32
30 min every 2 hrs	460-300	290-25	28	Open	135	469	29
20 min every 2 hrs	400-300	260-30	27	Open	141	299	47
15 min every 1½ hrs	450-350	330-40	26	Open	154	406	38

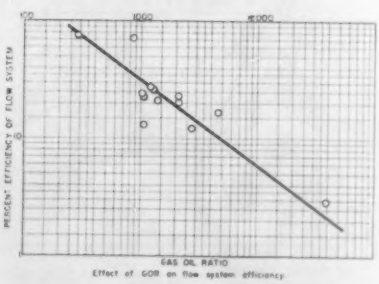

Fig. 6 — Effect of GOR on flow system efficiency.

ficient accuracy for approximating gas volumes drawn from the annulus during a flow cycle. The actual amount of gas used (cu ft/bbl/1,000 ft of lift) is calculated from Equation 1.

Equation 1

$$\text{Actual gas used (cu ft/bbl/1,000 ft)} = \frac{\text{Gas from casing annulus per cycle (cu ft)}}{\text{Fluid lifted (bbl)} \times \text{setting depth of piston (1000's of ft)}}$$

The theoretical gas requirement is determined using the isothermal work of expansion of the gas from the highest annular pressure to the average tubing pressure.

Equation 2

$$\text{Theoretical gas requirement (cu ft/bbl/1000 ft)} = \frac{\text{lbs/bbl} \times 1{,}000 \text{ ft}}{\text{Expansion work (ft lbs/cu ft)}}$$

From Table 2, it can be seen that in most instances as the casing pressure decreased, the theoretical gas requirements also decreased. As shown previously, theoretical gas requirements were computed from expansion energy while actual gas used was computed from the change in gas volume in the casing annulus. It should be noted that this latter value includes the work necessary to overcome all frictional resistance present in the tubing while this same resistance is neglected in calculating the theoretical gas volume requirement.

The very low values of the actual lift gas requirements for the 14½- and 6-hour flow periods are due to the fact that only pressure drops and no time factors were taken into account. Based on observations, approximately 22 minutes are required for the free piston to surface from 7,000 ft. If the flow-line valve is allowed to remain open after the piston reaches the surface, the casing pressure continues to bleed down to a certain point, depending upon the choke size, and then levels off. Inasmuch as only the overall pressure drop was considered in calculating the gas volumes rather than the pressure at the instant the piston reached the surface, the small gas requirement is due to use of the lower pressure with a resultant increase in expansion work.

It can be seen that Well No. 2 has a much lower theoretical lift ratio than Well No. 1, which is due to the choke being open and the gas expanding to a lower pressure, thus securing additional work of expansion.

It is interesting to note that the actual gas required for lift is essentially the same for both wells. If the assumption that the casing supplies all the lift gas is valid, the theoretical lift ratio can be taken as approximately 225 cu ft/bbl/1,000 ft of depth and the actual gas requirements taken as 400 to 450 cu ft/bbl/1,000 ft of lift. No attempts were made to evaluate the frictional resistance of the tubing, for it would be of little significance as it would pertain to only the two wells in question.

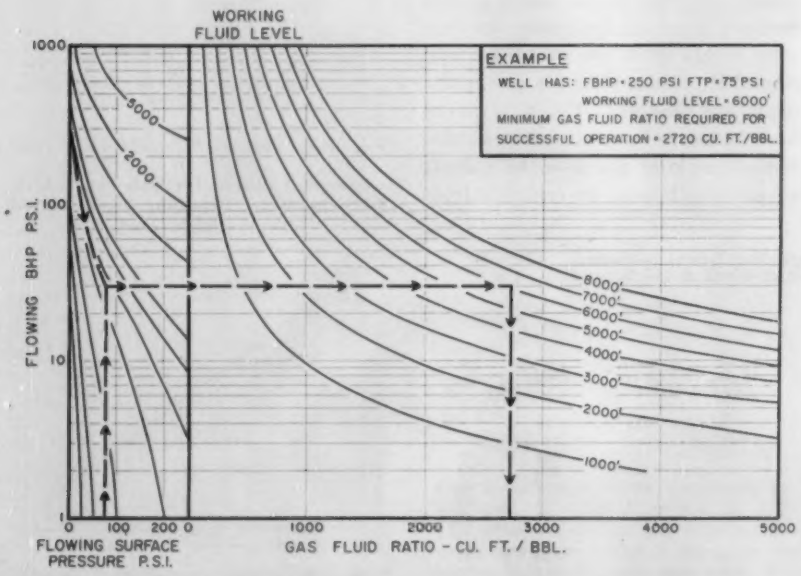

Fig. 7 — Nomograph for estimating limits of free piston application.

In order to verify the contention that the casing acts as a storage chamber for almost all the lift gas, a gas balance was made for a 24-hour period on two wells. These pertinent data and gas balances are as shown in Table 3.

TABLE 3

Well No. 1

Piston Setting Depth — 6,700 ft
Production — 39 bbl of oil
Flow Cycle — 22 minutes every hour
Fluid Produced per cycle — 1.625 bbl
Gas-oil ratio — 5,660 (metered)
Total gas produced/cycle — 9,240 cu ft
Net tubing volume allowing for fluid buildup — 128 cu ft
Amount of gas in tubing at start of cycle — 4,900 cu ft
Tubing pressure — 550
Lift gas furnished by casing — 5,150 cu ft
Total gas account/cycle — 10,050 cu ft
Deviation $\frac{10{,}050 - 9{,}240}{9{,}240} \times 100 = 8.9$ per cent

Well No. 2

Piston Setting Depth — 7,000 ft
Production — 28.29 BOPD; 2.07 BWPD
Flow Cycle — 20 minutes every 2 hours
Fluid Produced per cycle — 2.53 bbl
Gas-Oil Ratio — 3,000:1 (metered)
Total gas produced/cycle — 7,060 cu ft
Net Tubing volume allowing for fluid buildup — 139 cu ft
Amount of gas in tubing at start of cycle — 2,730 cu ft
Tubing pressure — 275
Lift gas furnished by casing — 5,170 cu ft
Total gas accounted/cycle — 7,900 cu ft
Deviation $\frac{7{,}900 - 7{,}060}{7{,}060} \times 100 = 11.9$ per cent

The 9 per cent and 12 per cent deviation between actual gas produced and that accounted for by calculations is considered to be well within limits of method of accuracy, particularly as no corrections for temperature and density were made in the gas volume calculations.

Producing gas-oil ratios, shown in Table 1, have shown a reduction after installing the free piston as compared with unassisted flow. Gas-oil ratio is an inherent function of reservoir behavior and characteristics and it is difficult to present a plausible theory in explanation of these results. The gas measurements have been made carefully within the limits of accuracy of techniques. The order of magnitude of differences is too high to be ascribed to measurement errors. The data are presented therefore as a factual reporting of the information collected.

Piston vs Intermitters

In order to determine the effectiveness of the free piston as compared to stopcock flow, the free piston was removed and Well No. 1 allowed to flow on the same time cycle using the intermitter alone. Production dropped from 34 to 26 BOPD during the 13-day period in which the piston was removed. Immediately after rerunning this tool, the production increased to 31

BOPD and the following day to 32 BOPD, at which time the test was discontinued.

Based on these tests, it is believed that a straight intermitting cycle cannot produce as much oil as a free piston installation in a solution gas reservoir. It is furthermore believed that, in the case of a well which produces water, the removal of the free piston will bring about a more pronounced decrease in production than that in the above well which produced no water. The reason for this is that the water being heavier than the oil will tend to drop downhole through the rising gas column until eventually the hydrostatic head will exceed the formation pressure and the well will cease to flow.

Cost

Based on data obtained, it is believed that the free piston can prolong the flowing life of a well and thus pay out the investment of approximately $1,000 per well, at the same time delaying and in some cases eliminating the expenditure of up to $15,000 for a pumping installation. Pumping units have been replaced by the free piston in three of the West Texas wells in which the main function of the pump was to agitate the well and remove the water from the bottom. Value of the salvaged equipment equals approximately $33,000 for the three wells. The installation of the free piston requires setting a stop or using the seating nipple, if the well has been on the pump.

The total installation cost for the free piston, including the time cycle control and surface lubricator, as well as installing the bottom stop, is approximately $1,000, which is considerably less than that required for any other method of artificial lift. The use of the plunger can be justified by a savings in operating costs alone.

Another advantage to the use of the free piston is in preventing paraffin accumulation in the wells. Some wells in which the tool has been installed required paraffin removal by scraping before installing the tool. There has been no necessity for scraping paraffin after the installation of the tool which contributes to the payout.

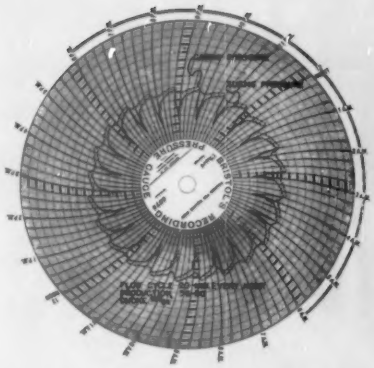

Fig. 8 — Casing and tubing pressure behaviors during the flow cycle.

Limitations

As mentioned previously, the average velocity obtained in the installations has varied from 250 ft to 650 ft per minute. Based on these data alone, a maximum production of approximately 80 B/D of fluid can be realized with the 2 in. piston. At present, 70 BOPD from approximately 8,000 ft is the maximum daily production being obtained continuously in the operations observed. However, this figure may be increased somewhat in future installations.

Pressured Bellows Controlled Free Piston

The previously mentioned Type 1 piston is used to improve the efficiency of intermittent gas lift operations. The pre-pressured metallic bellows controls the expansion and contraction of the sealing element of the piston.

Between the cycles of operation the piston rests in the bottom of the tubing with the seal contracted. When a pre-determined head of well fluid accumulates above the piston, the bellows is compressed expanding the seal. High pressure gas is then injected under the piston and the fluid delivered to the surface. When the fluid head has been removed from the tubing and the tubing pressure bled down below the pressure charge of the bellows, the bellows elongates, the seal contracts and the piston returns to the bottom for the next cycle of operation.

A number of installations of this type of free piston are in routine operation in different oil fields of the country. Last year a three-month test of the piston was performed in a well in southern Oklahoma. The well was previously produced with a reciprocating type subsurface pump. Overall piston efficiencies of around 40 per cent were indicated. It is interesting to note that attempts were unsuccessful to obtain comparison in the same well of operation of the piston with conventional intermittent gas lift. Because of severe paraffin conditions, the well could not be produced satisfactorily with conventional intermittent gas lift, while the travel of the piston kept the tubing free of paraffin.

Conclusions

An innovation of an old method of artificial lift has been presented. Data have shown that by the use of the tool a large capital investment of other types of artificial lift installations can be deferred or eliminated in many wells producing from volumetric type reservoirs and at the same time, the cost of the free piston can be amortized within one year through the savings in operating costs alone. The tool is not an answer to all producing problems; however, based on the results to date, satisfactory operation can be secured in many wells producing from solution gas drive reservoirs.

Acknowledgment

The authors of this paper gratefully acknowledge permission of Stanolind Oil and Gas Co. for publication and the work of all individuals of the organization who made preparation of the paper possible.

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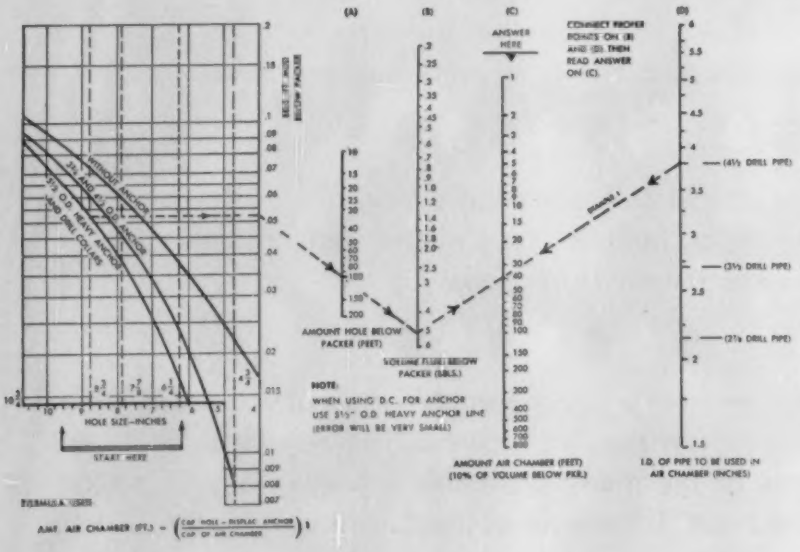

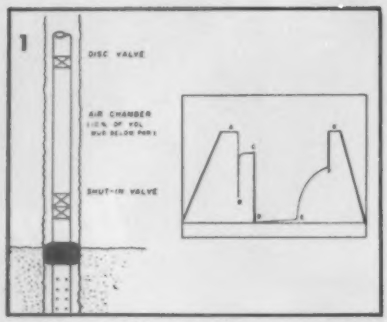

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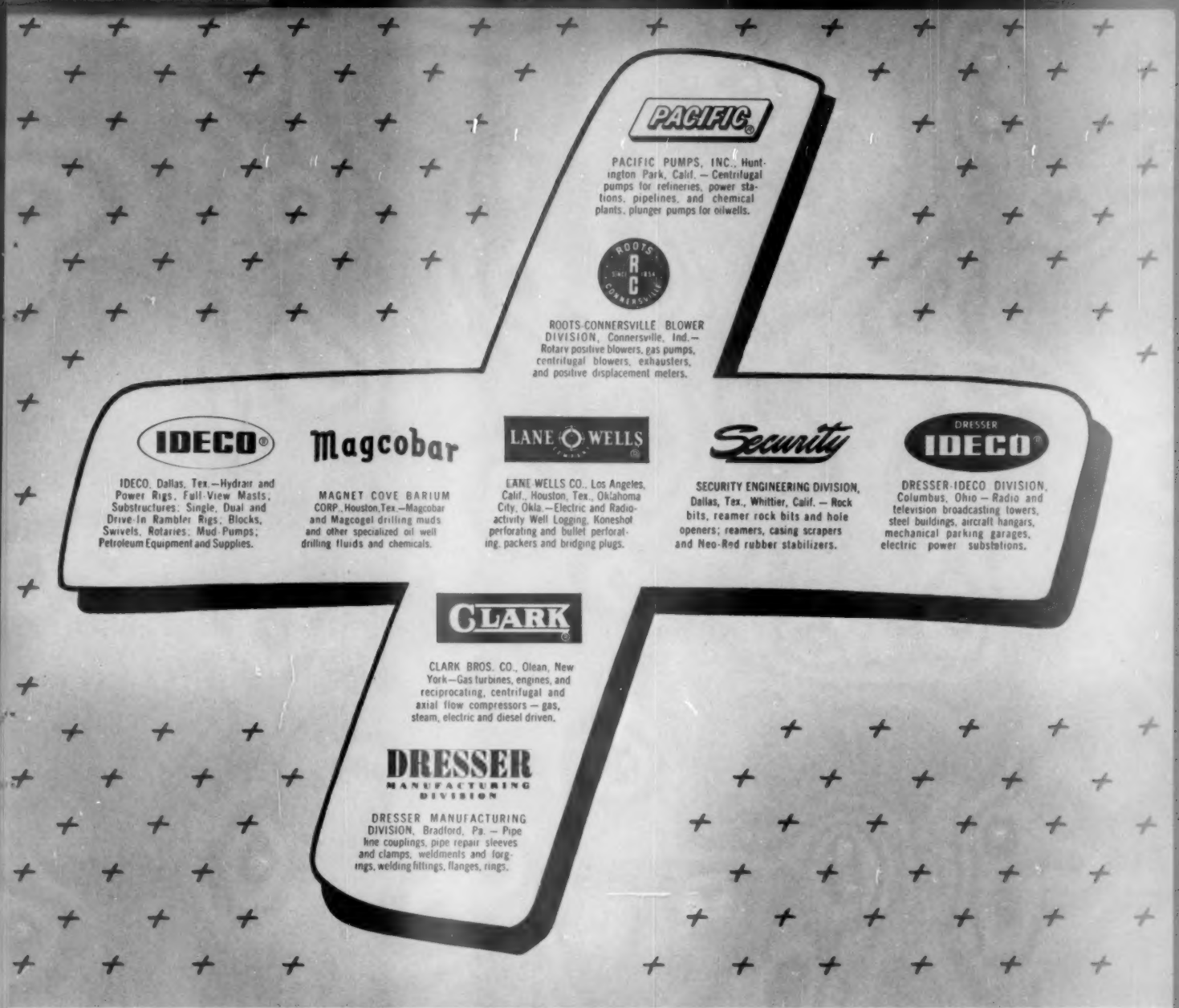
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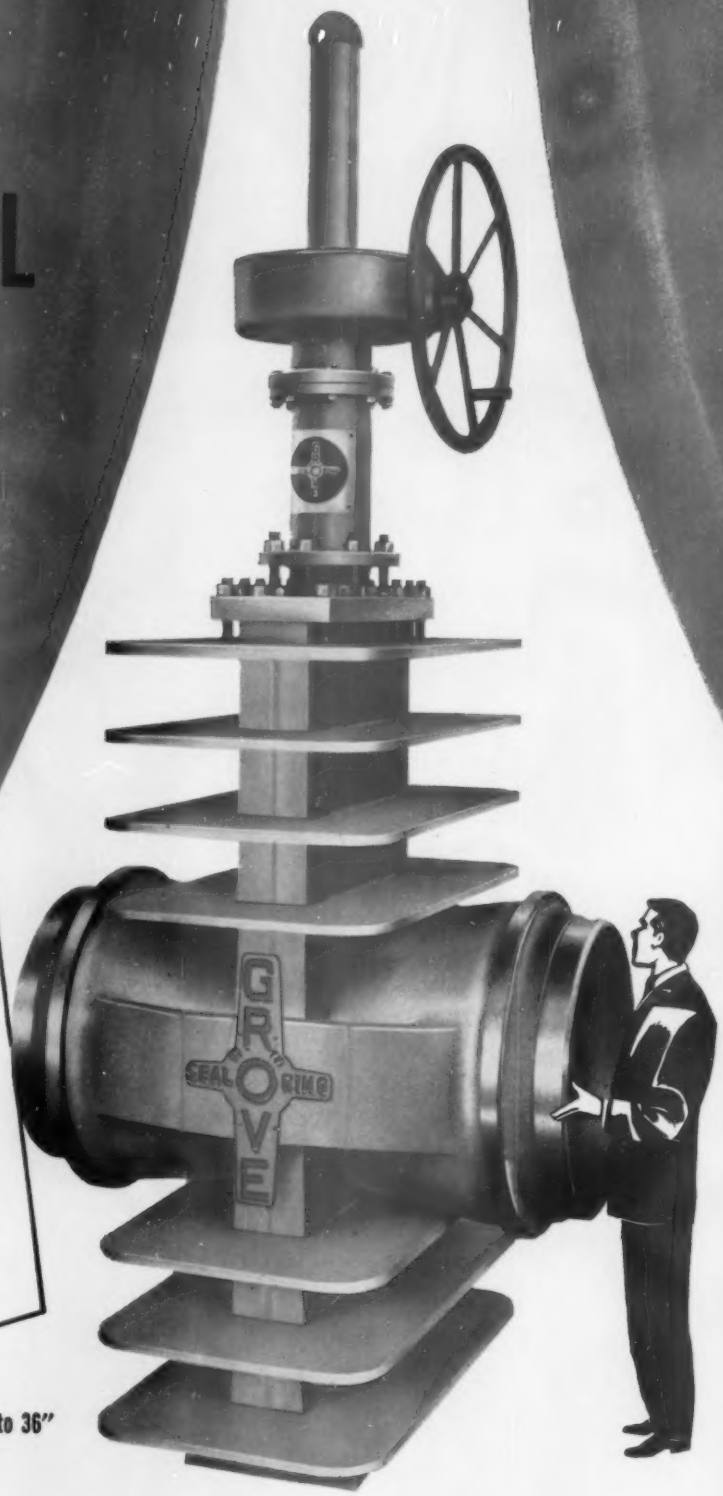

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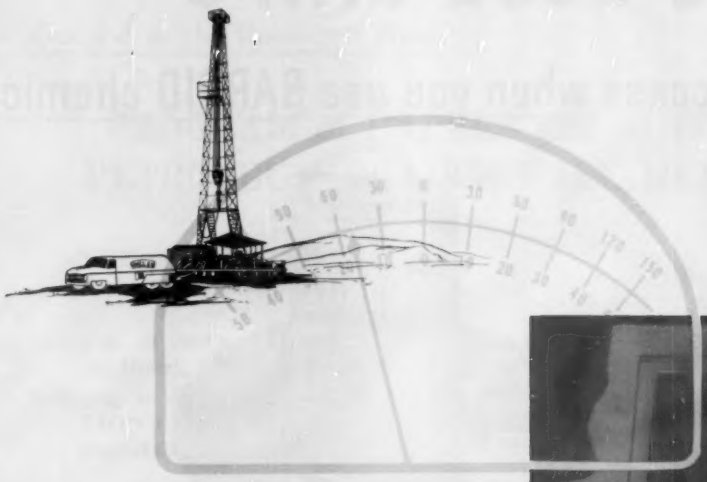

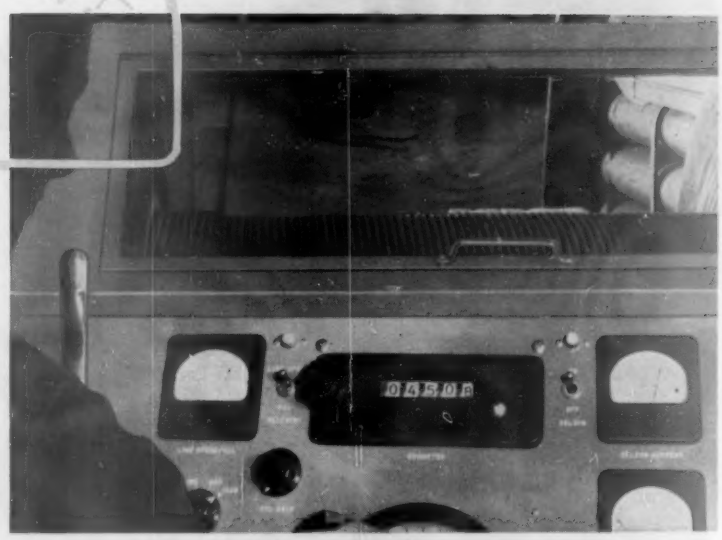

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Oct. 2-5 at the Roosevelt Hotel

PROGRAM of PAPERS and ACTIVITIES COMPLETED for PETROLEUM BRANCH FALL MEETING in NEW ORLEANS

Sunday, October 2

1:00 p.m. to 6:00 p.m. — REGISTRATION — University Room, 2nd Floor, Roosevelt Hotel

2:30 p.m. to 4:30 p.m. — AIME PETROLEUM SECTION CONFERENCE — International Room, Roosevelt Hotel

Monday, October 3

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS

9:00 a.m. to 10:45 a.m. — PRODUCTION EQUIPMENT — Roosevelt Ballroom

501-G: *Plunger Lift Correlation Equations and Nomographs*, CARROL M. BEESON, University of Southern California

509-G: *A Flowmeter for Measuring Subsurface Flow Rates*, J. L. NEWMAN, H. L. SAUDER, and COURTNEY WADDELL, Lane-Wells Co.

528-G: *A Review and Analysis of Equipment for Running Electrical Cables Under Pressure*, A. C. H. COOKE, Lane-Wells Co.; CECIL B. GREER, Bowen Co. of Texas, and F. L. SCOTT, JR., Dia-Log Co.

9:00 a.m. to 11:45 a.m. — LOGGING — Roosevelt International Room

500-G: *Displacement Logging — A New Exploratory Tool*, W. M. CAMPBELL and J. L. MARTIN, The Atlantic Refining Co.

503-G: *Neutron Log Correction Charts for Borehole Conditions and Bed Thickness*, by J. T. DEWAN, Schlumberger Well Surveying Corp.

523-G: *Spectral Gamma-Ray Logging*, H. R. BRANNON, JR. and J. S. OSOBA, Humble Oil and Refining Co.

532-G: *Effect of Clay and Water Salinity on Electrochemical Behavior of Reservoir Rocks*, H. J. HILL and J. D. MILBURN, Shell Oil Co.

12:15 p.m. — PETROLEUM BRANCH WELCOMING LUNCHEON — Roosevelt Ballroom. Speaker: Henry F. Holland, Assistant Secretary of State for Inter-American Affairs. Presiding: Earl M. Kipp.

3:00 p.m. — LADIES SHERRY-COFFEE — Petroleum Club of New Orleans, Shell Building

2:15 p.m. to 5:00 p.m. — FLUID MECHANICS — Roosevelt International Room

502-G: *Displacement of Oil by Water — Effect of Wettability Rate and Viscosity on Recovery*, T. F. MOORE, and R. L. SLOBOD, The Atlantic Refining Co.

511-G: *Wettability Versus Displacement in Water Flooding in Unconsolidated Sand Columns*, JACK NEWCOMBE, JOHN MCGHEE and M. J. RZASA, Cities Service Research and Development Co.

518-G: *A Comparison of Field k_g/k_o Characteristics and Laboratory k_g/k_o Test Results Measured by a New Simplified Method*, W. W. OWENS, D. R. PARRISH, and W. E. LAMOREAUX, Stanolind Oil and Gas Co.

542-G: *Experimental Waterflooding Recoveries at Pressures Above and Below the Bubble Point*, D. M. BASS, JR. and PAUL B. CRAWFORD, Texas Petroleum Research Committee

2:30 p.m. to 5:00 p.m. — SLIM HOLE DRILLING — Roosevelt Ballroom

506-G: *An Engineering Appraisal of Small Diameter Hole Drilling in Soft Rock Operations*, J. H. FAULK, The Atlantic Refining Co.

512-G: *Industry Attitudes Toward Slim Hole Drilling*, by P. L. MCLAUGHLIN, Cardwell Manufacturing Co., Inc.

529-G: *Development of Services and Equipment for Small Holes*, T. A. HUBER, Humble Oil and Refining Co.

516-G: *New Developments in the Control of Lost Circulation*, P. P. SCOTT and J. L. LUMMUS, Stanolind Oil and Gas Co.

6:00 p.m. — "STEAMBOATIN' DOWN THE MISSISSIPPI" — FOR LADIES AND MEN — BUFFET SUPPER AND DANCE DURING STEAMER RIDE ON MISSISSIPPI — Delta Section, Hosts

Tuesday, October 4

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS

9:00 a.m.-11:45 a.m. — INFORMAL CONFERENCE ON ELECTRICAL LOGGING IN SHALY SANDS — University Room, Roosevelt Hotel. Presiding: K. S. Spiegler, Gulf Research and Development Co.

8:30 a.m. to 11:15 a.m. — CEMENTING — Orpheum Theater

508-G: *A New Material for Deep Well Cementing*, DWIGHT K. SMITH, Halliburton Oil Well Cementing Co.

519-G: *Problems in Casing Collapse*, G. N. MURCHEY, Creole Petroleum Corp.

522-G: *An Accelerated Squeeze-Cementing Technique*, G. K. DUMBAULD, D. PERRY, F. A. BROOKS, JR., and G. W. BINKLEY, Humble Oil and Refining Co.

530-G: *A New Retrievable Wire Line Cementing Tool*, BLAKE M. CALDWELL and GEORGE E. BRIGGS, JR., Welex Jet Services, Inc.

9:00 a.m. to 10:45 a.m. — ECONOMICS AND GENERAL INTEREST—Roosevelt International Room

551-G: *The Near-Term Supply and Demand Outlook for the Petroleum Industry*, JOHN G. WINGER, Chase Manhattan Bank

552-G: *Objectives of Engineering Education,* WILLIAM V. HOUSTON, Rice Institute

541-G: *Northeast Butterly Pool — Case History,* S. D. MCCLOUD, JACK MARSHALL, and ROY BUTLER, Continental Oil Co.

11:45 a.m. — LADIES LUNCHEON AND STYLE SHOW — Roosevelt Ballroom

12:15 p.m. — PETROLEUM BRANCH MEMBERSHIP LUNCHEON — Roosevelt International Room. Brief Reports on AIME Activities by President H. DeWitt Smith and on Petroleum Branch Activities by Branch Chairman Robert B. Gilmore. Door prize: $65 spin fishing rod and reel, Sila-Flex glass rod and Langely lightweight reel — compliments of the Delta Section

2:30 p.m. to 5:00 p.m. — DRILLING — Roosevelt International Room

557-G: *Flow Properties of Suspension in Drilling Mud Design,* W. C. BROWNING, Marathon Corp.

505-G. *Effect of Mud Column Pressure on Drilling Rates,* A. S. MURRAY, Imperial Oil Ltd., and R. A. CUNNINGHAM, Hughes Tool Co.

525-G: *Lost Circulation Information Obtained with a New Tool for Detecting Zones of Loss,* T. BARDEEN and A. J. TEPLITZ, Gulf Research & Development Co.

540-G: *Development and Testing of Jet Pump Pellet Impact Drill Bits,* J. E. ECKEL, F. H. DEILY, and L. W. LEDGERWOOD, JR., The Carter Oil Co.

2:45 p.m. to 5:00 p.m. — MODELS AND ANALOG COMPUTERS — St. Charles Hotel Ballroom

507-G: *The Determination of the Water Injection Program for the Delhi Field by Means of the Automatic Multi-Pool Analyzer,* O. L. PATTERSON, Sun Physical Research Lab., C. G. O. DUTTON and H. E. ELLIS, Sun Oil Co.

534-G: *An Analog Computer for Studying Heat Transfer During a Thermal Recovery Process,* L. C. VOGEL and R. F. KRUEGER, Union Oil Co. of California

537-G: *The Application of the Gelatin Model for Studying Effects of Mobility Ratio,* PAUL B. CRAWFORD, and MELVEN BURTON, Texas Petroleum Research Committee

539-G: *Theory of Dimensionally Scaled Models of Petroleum Reservoirs,* G. A. CROES, J. GEERTSMA and N. SCHWARZ, Koninklijke/Shell-Laboratorium, Amsterdam

7:00 p.m. — PETROLEUM BRANCH BANQUET AND DINNER DANCE — Roosevelt Ballroom and International Room. Music by two orchestras, Rene Lauapre and Russ Papalia. Dress: Dark suits or tuxedos for men, cocktail or evening dresses for the ladies

Wednesday, October 5

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS

9:00 a.m.-11:30 a.m. — OPEN MEETING PETROLEUM BRANCH EDUCATION COMMITTEE — Creole Room, Roosevelt Hotel; A. W. Walker presiding

8:30 a.m. to 11:45 a.m. — FLUID MECHANICS — Roosevelt Ballroom

510-G: *Influence of Rock and Fluid Properties on Immiscible Fluid Flow Behavior in Porous Media,* F. E. MERLISS, J. D. DOANE and M. J. RZASA, Cities Service Research and Development

517-G: *The Determination of Partial Pressure Maintenance Performance by Laboratory Flow Tests,* F. F. CRAIG, JR., and T. M. GEFFEN, Stanolind Oil & Gas Co.

536-G: *Mechanism of Water Flooding in the Presence of Free Gas,* J. R. KYTE, R. J. STANCLIFT, S. C. STEPHAN and L. A. RAPOPORT, The Carter Oil Co.

545-G: *Determining Gravity Drainage Characteristics on the Centrifuge,* J. W. MARX, Phillips Petroleum Co.

8:30 a.m. to 12:00 m. — WELL COMPLETION — Roosevelt International Room

526-G: *A New Method for Controlling Incompetent Sands,* J. K. HENDERSON, W. L. SALLEE, and C. M. STOUT, Dowell Incorporated

531-G: *Friction Loss of Fracturing Fluid,* C. O. BUNDRANT, and THOMAS A. MATTHEWS, II, The Western Co.

533-G: *Some Aspects of Sand-Oil Fracturing in Long Heterogeneous Sand Sections,* LEJEUNE WILSON, International Petroleum Co., Ltd.

514-G: *Design of Casing Strings,* C. N. BOWERS, Gulf Research and Development Co.

496-G: *The Effect of Fluid Loss on Fracture Extension,* J. G. DAVIS, J. J. REYNOLDS, and H. F. COFFER, Continental Oil Co.

8:30 a.m. to 11:15 a.m. — GAS TECHNOLOGY — Orpheum Theater

524-G: *Analysis of Low-Temperature Separation Plants,* H. E. STAMM, and D. G. MCCARTHY, Humble Oil and Refining Co.

538-G: *Effect of Pressure, Temperature, and Wellstream Composition on the Quantity of Separator Fluid,* WILLIAM E. PORTMAN, and JOHN M. CAMPBELL, The University of Oklahoma

544-G: *Simultaneous Flow of Liquid and Gas Through Horizontal Pipe,* A. F. BERTUZZI, M. R. TEK and F. H. POETTMANN, Phillips Petroleum Co.

1:30 p.m. to 4:30 p.m. — RESERVOIR ENGINEERING — Roosevelt Ballroom

520-G: *Performance Calculations for Combination Drive Reservoirs,* L. D. WOODDY, JR., and ROBERT MOSCRIP III, Humble Oil and Refining Co.

521-G: *Recovery of Oil by Condensing Gas Drive,* H. L. STONE and J. S. CRUMP, Humble Oil and Refining Co.

535-G: *Gas Drive and Gravity Drainage Analysis for Pressure Maintenance Operations,* D. R. SHREVE and L. W. WELCH, JR., The Carter Oil Co.

1:30 p.m. to 4:30 p.m. — PRODUCTION OPERATIONS AND ENGINEERING — Roosevelt International Room

513-G: *A Practical Method for Treating Oil-Field Interference in Water-Drive Reservoirs,* M. MORTADA, Magnolia Petroleum Co.

515-G: *Removal of Sulfides from Brine by Aeration With Exhaust Gases from Submerged Combustion,* W. J. HART, and R. G. WINGATE, Gulf.

527-G: *Successful Conditioning of Pacific Ocean Water for Waterflood Injection,* J. D. SUDBURY, C. F. KNUTSON, MARTIN FELSENTHAL and J. D. LUNG, Continental Oil Co.

★★★

Technology Committee Creates Problem—Then Solves It to Formulate Fall Meeting Program

L. P. Whorton

L. P. "Barney" Whorton and his Technology Committee faced a stack of 78 papers when they sat down on May 6 for an all-day meeting to formulate the Fall Meeting technical program. Less than two-thirds of them could be accepted for presentation because of time limitations in the three-day program.

The Technology Committee members had no one but themselves to blame for the problem, however, for they had searched the industry for papers to be considered for the program. Their search had begun on Jan. 28, 1955, after the first meeting of this committee.

They contacted the oil companies, the universities, and consultants in an effort to seek out the best possible papers for the 1955 Fall Meeting program. Now they had the problem of selecting only a portion of them for presentation, declining the rest.

R. K. Guthrie

J. H. Thacher

Seated around the table with Whorton at the May meeting were: R. K. Guthrie, Seeligson Engineering Committee, and R. G. Parker, Continental, production engineering vice-chairmen; R. A. Morse, Gulf, and A. F. van Everdingen, Shell, reservoir engineering vice-chairmen; and Roy A. Bobo, Phillips, drilling vice-chairman. John H. Thacher, California Research Corp., petroleum economics vice-chairman, was not present, but had made his comments available to the committee.

A. F. van Everdingen

R. A. Morse

Reasonably complete descriptions were available for all papers to be considered: a not less than 200 word abstract and the author's answers to six questions concerning the contribution which the paper offered. Each committee member had rated the papers as excellent, average, or below average and had written general comments on the merits of each paper. This information was before the committee members as they cast their vote—to accept for presentation or decline.

By 5 p.m. on May 6, 47 papers had been accepted for the program. Papers not accepted for presentation at meeting were requested to be submitted for consideration for publication, but only a limited number could be placed on the three-day New Orleans program. Even after this careful selection, the number of papers chosen requires that three concurrent technical sessions be held one morning of the meeting and two concurrent sessions throughout.

R. G. Parker

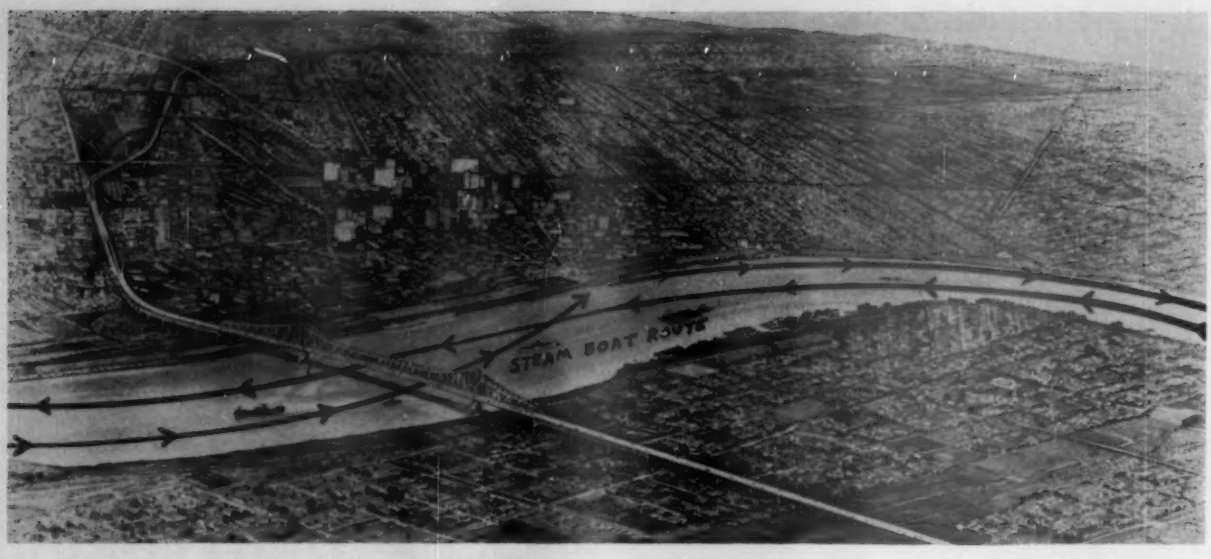
Roy A. Bobo

A good technical program makes a good Fall Meeting. Also, top quality papers presented there insure high reader interest in JOURNAL OF PETROLEUM TECHNOLOGY when they are published. The Branch is indebted to the excellent work done by the Technology Committee in assembling a strong, well-balanced technical program for the 30th Annual Petroleum Branch Fall Meeting.

INFORMAL CONFERENCE on LOGGING in SHALY SANDS

An informal conference on electrical logging in shaly sands will be held in the University Room of The Roosevelt Hotel on Tuesday, Oct. 4, from 9 a.m. to 11:45 a.m. K. S. Spiegler of Gulf Research and Development Co. will preside.

Electrical logging in shaly sands has received considerable attention in recent years. No new papers on the subject are scheduled for presentation at Fall Meeting technical sessions; therefore, it was considered worthwhile to hold an informal meeting to bring authors of previous papers together to discuss the problem. Since so many different theories have been advanced through recent publications, this type of conference should be of wide interest.



Fall Meeting City—Romantic New Orleans

More than any other city, New Orleans gives the visitor a feeling that he is both in the United States and out of it. From handsome, wide Canal Street, busy with modern stores, one can walk a block and perceive the atmosphere of old France and old Spain. This one-block walk takes the sightseer into the quaint French Quarter, famous for its old world atmosphere and romantic tradition.

The narrow streets, sloping roofs, shaded patios, elaborate iron balconies, fan windows, and mysterious alleys make the French Quarter distinct and interesting. Fabulous Bourbon Street with its gay night life is the central point of activity after dark, but Jackson Square, the St. Louis Cathedral, the Cabildo, and the Presbytere are points of historical interest in the Quarter during the day.

The city was founded by the French in 1718 and later came under the domination of the Spanish. When in 1903 New Orleans became an American city, it was steeped in Latin tradition. The French and Spanish inhabitants, proud of their heritage, were resentful of any attempt to impose a new system upon their city. So, with the influx of Americans, a new colony was established on the opposite side of Canal Street from the French Quarter. This dividing line still remains, with the Quarter spralling from the River to Rampart Street and from Canal to Esplande Avenue, surrounded on all sides by modern New Orleans.

Fall Meeting visitors will have a fine opportunity to view New Orleans as a seaport during the cruise on the steamer "President" scheduled for Monday night. Part of the 30-mile route of the boat is shown in the picture of the city on this page. The entire boat has been reserved for Fall Meeting guests—with a buffet supper and music by local orchestras planned. Those attending this affair will have the choice of dancing or seeing the sights of New Orleans harbor.

When Fall Meeting guests find the time, they can visit some of the internationally famous restaurants. New Orleans has been called the gourmet's capital of the world, for it has restaurants featuring fine French, Creole, Italian, Mexican, and Chinese foods.

With its contrast of an old and new civilization, there is no other city like New Orleans. The Fall Meeting visitor who has never before been there can expect a treat; those who have visited there previously know that no word-description does justice to this fascinating city.

Much of the night life of New Orleans is centered around Bourbon Street in night clubs which feature Dixieland jazz music which had its birth in that city. Seen here is the street bus Desire which recently replaced the street car of that name. The old building on the left is the famous Absinthe House, erected in 1806. The photograph at the top of the page is an architect's drawing of New Orleans including the new Mississippi Bridge now under construction. The Steam Boat Route marking indicates part of the trip to be covered in the "Steamboatin' Down the Mississippi" party Monday night, Oct. 3.

For the Ladies: Crescent City Hospitality

The Crescent City displaying its "Sunday best" southern hospitality promises to provide an enjoyable setting for the Fall Meeting of the Petroleum Branch, AIME, October 2-5. The continually growing attendance of wives of AIME members at the annual Fall Meetings has resulted in a schedule of carefully planned activities for the more than 700 ladies who plan to attend the meeting this year.

Mrs. W. A. Todd, general chairman of the ladies' activities, and her committee have planned a program of events that will keep the ladies as busily and interestingly engaged as their husbands are in the technical aspects of the meeting.

Wardrobe Planning

Wardrobe planning for the meeting should not be difficult since all of the functions will be in air-conditioned rooms except, of course, the steamer ride. However, Mrs. Todd suggests a few tips that may be helpful. The weather in New Orleans will probably be warm but there is always the chance of a "Norther" so a light wrap would be recommended. For daytime wear, winter cottons are well suited for the climate since they are cool but have a Fall look. A light suit is also appropriate since the jacket can be removed.

All AIME events will be held in the Roosevelt Hotel or nearby, but comfortable walking shoes should be included for personal sightseeing trips to the French Quarter. The Petroleum Branch dinner dance will be semi-formal, the men may wear business suits and the women cocktail or formal dresses.

Sherry-Coffee

A Sherry-Coffee will welcome the ladies Monday, October 3, from 3 to 5 p.m. at the new Petroleum Club. This type of party is traditional in New Orleans and is similar to a tea or coffee in other parts of the country. Tea and coffee will be served in addition to sherry. No transportation will be necessary as The Roosevelt is centrally located and you can go just around the corner to the Shell Building entrance and up their elevator to the third floor.

After the Sherry-Coffee the ladies will join their husbands and go a short distance from the Petroleum Club to the base of Canal Street to board the Steamer President for a buffet supper and dance. A Dixieland band will begin playing at 6:00 and bands will provide music for dancing on two decks of the steamer. Free beer and soft drinks will be available and a wide variety of hot and cold food will be served cafeteria style. The women will wear what they wore to the Sherry-Coffee, as the dance will be informal.

Fashion Show and Luncheon

The AIME fashion show luncheon will be held at 11:45 a.m., Tuesday, October 4, in the Grand Ballroom of the Roosevelt Hotel. The Gus Mayer Co., Ltd. is sponsoring the show. All types of Fall clothes will be shown from sports wear and street clothes to cocktail and formal dresses. All the clothes will be selected from the store's best lines and a member of their fashion department will moderate.

Tuesday evening the AIME banquet and dinner dance will begin at 7:00 p.m. in the Grand Ballroom and adjoining International Room at the Roosevelt Hotel. The entertainment committee has worked especially hard on this event providing two good bands and a floor show.

Hospitality Suite

A Ladies Hospitality Suite will be provided in the new part of The Roosevelt where coffee will be served and questions answered. It is an especially good place for those who are staying out in town to freshen up. The Suite will be open Monday and Tuesday from 10 to 4 and Wednesday from 10 to 2.

The wives of the Petroleum Branch members have always been welcome at Branch Meetings, and we are exceptionally proud to welcome the record attendance of ladies this year.

ANN KROCHMAN

Elaborately designed ironwork, much of which was imported from Spain, decorates many of the homes in the French Quarter. Above is a view of Orleans Street looking toward the rear of the famous St. Louis Cathedral.

Practically every home in the original section of New Orleans has its patio. Fountains, tropical foliage, flagstone pavement and large jars in which olive oil was imported can be found in most of these patio gardens.

Oct. 20-21 in Los Angeles

SOUTHERN CALIFORNIA MEETING FEATURES 20 PAPERS

Twenty technical papers comprise the largest program in recent years for the Annual Fall Meeting of the Southern California Petroleum Section. The meeting will take place at the Biltmore Hotel, Los Angeles, Oct. 20-21.

Sam Grinsfelder, Union Oil Co., is the general chairman of the meeting. Program chairmen are Floyd E. Schoonover, Monterey, and Francis J. Barker, Union Oil Co. The October issue of JOURNAL OF PETROLEUM TECHNOLOGY will feature full information on this meeting, along with abstracts of the papers to be presented.

THE PROGRAM

THURSDAY, OCT. 20

8:30 a.m. to 5:00 p.m. — Registration and Exhibits — Lobby, Biltmore Hotel Ballroom.

9:15 a.m. — Welcoming Address — Chairman of Southern California Petroleum Section, H. M. Stanier, Sunray Mid-Continent Oil Co.

9:20 a.m. to 11:30 a.m. — PROGRESS SESSION

Chairmen: Sam A. Barclay, Humble Oil & Refining Co.
Floyd E. Schoonover, Monterey Oil Co.

9:20 a.m. — 562-G: *"Application of Hydraulic Fracturing to California Formations,"* VERNON R. YOUNG, Halliburton Oil Well Cementing Co.

9:55 a.m. — 563-G: *"Well Stimulation by Hydraulic Fracturing in California,"* JAMES L. BOWAN, Shell Oil Co.

10:30 a.m. to 11:10 a.m. — FORMATION FRACTURING FORUM

10:30 a.m. — 564-G: *"Fracturing the Basement Complex,"* W. M. STADTMILLER, Monterey Oil Co.

10:40 a.m. — 565-G: *"Response of a Cretaceous Sand to Hydrafrac,"* R. E. CORY, The Texas Co.

10:50 a.m. — 566-G: *"Injecting 1,300 Sacks of Sand into a California Formation,"* G. V. KERSTEN, Western Gulf Oil Co.

11:00 a.m. — 567-G: *"Application of Vertifrac through a Perforated Liner,"* J. D. LUNG, Continental Oil Co.

11:10 a.m. — *Audience Participation* — Questions are written on cards previously distributed to audience and are answered by person to whom question is directed.

12:00 m. — Petroleum Sections Luncheon and Annual Business Meeting
Luncheon Speaker: Robert B. Gilmore, De Golyer and MacNaughton, Petroleum Branch Chairman

2:00 p.m. to 5:00 p.m. — PETROLEUM SESSION

Chairmen: Francis J. Barker, Union Oil Co.
Ronald H. Newman, Long Beach Oil Development Co.

2:00 p.m. — 568-G: *"The Shifting Center of Petroleum Production,"* GRAHAM B. MOODY, Petroleum Consultant

2:35 p.m. — 569-G: *"Economics of Supplementing California Production with Crude Oil Imports,"* RUSSELL B. BROWN, Independent Petroleum Association of America

3:05 p.m. — 571-G: *"An Evaluation of Gas Injection in the Emery West Pool, West Coyote Field, California,"* SHELDON F. CRADDOCK, Standard Oil Co.

3:40 p.m. — 572-G: *"A Lightweight, Low Water-Loss, Oil Emulsion Cement for Use in Oil Wells,"* G. K. DUMBAULD, F. A. BROOKS, JR., B. E. MORGAN, and G. W. BINKLEY, Humble Oil & Refining Co.

FRIDAY, OCT. 21

8:30 a.m. to 4:30 p.m.—Registration and Exhibits—Lobby, Biltmore Hotel Ballroom

9:00 a.m. to 11:45 a.m. — THE ENGINEER SESSION

Chairmen: Nick van Wingen, Petroleum Consultant and professor at University of Southern California
Fred C. Stolz, Continental Oil Co.

9:00 a.m. — 573-G: *"Development of the Sansinena Field, California,"* C. F. BOWDEN, J. T. LEDBETTER, V. S. MOYER, Union Oil Co.

9:30 a.m. — 574-G: *"A Study of the Network Model of Porous Media,"* I. FATT, University Southern Calif. (California Research Corp.)

10:00 a.m. — 534-G: *"An Analog Computer for Studying Heat Transfer During a Thermal Recovery Process,"* L. C. VOGEL and R. F. KRUEGER, Union Oil Co.

10:30 a.m. — 575-G: *"An Evaluation of Bottom-Hole Heating on Well Performance,"* T. S. MELBY, Shell Oil Co.

11:00 a.m. — 576-G: *"Comparison of Pressure Distribution During Depletion of Tilted and Horizontal Reservoirs,"* D. S. HOWARD, JR., and H. H. RACHFORD, JR., Humble Oil & Refining Co.

12:00 m. — All Sections Luncheon — Luncheon Speaker: Harrison S. Brown, Professor of Geochemistry, California Institute of Technology

2:00 p.m. to 4:30 p.m. — LOOKING AHEAD SESSION

Chairmen: Mortimer A. Kline, Petroleum Lawyer
Richard A. Holman, Amerada Petroleum Corp.

2:00 p.m. — 577-G: *"The New Law for California's Offshore Oil Development,"* THOMAS C. MORONEY, Honolulu Oil Corp.

2:30 p.m. — 578-G: *"Preparing to Drill Offshore in 300 Feet of Water,"* J. N. GREGORY, Terminal Drilling and Production Co.

3:00 p.m. — 579-G: *"Contract Drilling in Foreign Countries,"* J. D. ROBINSON, Santa Fe Drilling Co.

3:30 p.m. — 580-G: *"How to Get Ahead, Engineer,"* W. C. STEVENSON, Union Oil Co.

4:00 p.m. — 581-G: *"An Oil Man Looks at Atomic Energy,"* A. H. CHAPMAN and J. T. DUCE, Arabian American Oil Co.

7:30 p.m. — Southern California Petroleum Section Dinner Dance—Biltmore Hotel Ballroom

★★★

Mrs. W. A. Todd
Ladies Activities

J. J. Metzger, Jr.
Monterey
Finance

A. L. Vitter, Jr.
California Co.
Arrangements

W. B. Vice
Southern Tech.
Service, Inc.
Entertainment

Charles A. Capps
Wilson Supply Co.
Housing

Charles Doh
Schlumberger
Registration

B. W. Aulick
Halliburton
1st V.C.
Delta Section

W. D. Clift
Humble
2nd V.C.
Delta Section

E. H. Leeman
Shell Oil Co.
Secretary
Delta Section

K. J. Ebner
Texas Co.
Treasurer
Delta Section

B. L. Francis
Texas Co.
Chairman
Delta Section

E. M. Kipp, Jr.
California Co.
Welcoming
Luncheon

These Chairmen Planned Informative, Entertaining 30th Annual Fall Meeting

Problem: To plan a Fall Meeting which will retain high interest and participation among the visitors, even with fabulous New Orleans beckoning.

Solution: Utilize the attractions of the city to best advantage in arranging a program that overshadows all other interests.

The best Fall Meeting is one in which everyone participates in all scheduled functions, and that is where the problem arose in planning the 30th Annual Petroleum Branch Fall Meeting in New Orleans.

"We have to make every function so entertaining that our visitors will want to attend, rather than following other lures of the city" was the constant thought of Delta Section committees. Of course, they want all visitors to take time to see the Crescent City, but not at the expense of Fall Meeting functions.

With this problem uppermost in their minds, the meeting committees and Petroleum Branch staff planned the meeting so as to make attendance inviting and convenient. Good meeting rooms, centralized activities and the attractions of New Orleans were combined as to be of maximum interest to everyone attending the meeting.

FALL MEETING EXHIBITORS' GUIDE

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Associated Equipment, Inc.	19
Atomic Energy of Canada, Ltd.	11
B & W, Inc.	8
Baker Oil Tools, Inc.	13
Brown Oil Tools, Inc.	14
Camco, Inc.	25, 26
Cherokee Laboratories, Inc.	24
Communications Engineering Co.	10
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Diamond Oil Well Drilling Co.	18
Dowell Incorporated	30
Dresser Industries, Inc.	28
Garrett Oil Tools, Inc.	2
Geophysical Research Corp.	16, 17
Halliburton Oil Well Cementing Co.	29
Hycalog, Inc.	15
Johnston Testers, Inc.	3
Keystone Development Corp.	9
Lane-Wells Co.	27
McCullough Tool Co.	22, 23
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National Supply Co.	20
Orbit Valve Co.	1
Otis Pressure Control, Inc.	12
Schlumberger Well Surveying Corp.	5
Shaffer Tool Works	31
Welex Jet Services, Inc.	4

you're always welcome at Camco's booths

stop a bit and rest awhile at Camco's AIME Fall Meeting booths, 25 and 26, at the Roosevelt Hotel in New Orleans October 2-5.

it will give you an opportunity to leisurely study a line-up of conventional and wire line retrievable valves and mandrels, the latest in dual completion retrievable gas lift equipment, and the all-new, low-cost "K" Series valves and mandrels.

and between chatting with old friends and meeting new ones, sip a cup of coffee or a tall, cool one with us at our open house.

Henry F. Holland, Assistant Secretary of State for Inter-American Affairs, to Speak at Oct. 3 Welcoming Luncheon

Henry F. Holland, Assistant Secretary of State for Inter-American Affairs, will speak at the Fall Meeting Welcoming Luncheon at noon on Monday, Oct. 3. The subject of his talk will be "The Role of Private Investment in the Economic Development of Latin America."

Holland assumed his present office on March 2, 1954, at Caracas, Venezuela. For many years prior to becoming assistant secretary, he was responsible for the Latin American matters of the law firm of Baker, Botts, Andrews, and Shepherd.

From 1936 to June, 1942, Holland was in private law practice in San Antonio. Then, until Sept., 1945, he was a member of the Foreign Service Auxiliary assigned to the American Embassy in Mexico City.

He is a 1936 graduate of the Law School of the University of Texas. Earlier, in 1933, he had obtained his BA degree from University of the South, Sewanee, Tenn.

Since becoming Assistant Secretary for Inter-American Affairs, Holland has visited each of the 20 Latin American Republics, where he not only had an opportunity to become acquainted with their leaders but to carry on frank discussions of mutual problems. In Feb., 1955, he and Mrs. Holland accompanied the Vice-President and Mrs. Nixon on their good-will tour of Mexico, Central America, and the Caribbean.

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...speeds wire line operations

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CONTROL – The skill and stamina of the operator have been replaced by sensitive electronic instruments which accurately record every strain variation.

SPEED – Easy-to-assemble equipment, power and accuracy of operations combine to save production time and wire line operations time. A built-in testing panel saves on repair time.

POWER – Denison hydraulic motors provide a surface line pull of 1600 pounds maximum torque and retrieves tools from 12,000 feet at 1200 feet per minute. The unit is equipped with power controls for jarring down and the powerful new Bowen hydraulic jar for "jarring up."

With Camco's new Wire Line Service unit, you have these extra advantages:

Two trained Gas Lift operators, equipped with special Gas Lift testing equipment, make at-the-well tests and repairs.

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CAMCO

1001

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Supplementing the widely used MM Series, "K" Series valves and mandrels are designed for use in smaller casing sizes. The "K" Series Dual Completion mandrels simultaneously gas lift two zones in casing as small as 5½" - 17#, with all valves for both zones selectively retrievable.

You can depend on the all-new "K" Series Valves and Mandrels. They will meet any gas lift requirement in regular or permanent type well completions or dual retrievable gas lift installations.

Send for Brochure "K-55" and learn how you can save time and money with Camco's all-new "K" Series Valves and Wire Line Service.

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Send me Brochure "K-55" ☐ *Dual Completion Literature* ☐

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ADDRESS _____

COMPANY _____

CITY _____ STATE _____

Steamboatin', Dixieland Music

Fall Meeting Socials Feature New Orleans-Style Entertainment

Dixieland bands, shuffle tap dancers, sights of New Orleans Harbor at night, and free food and beer —all these will be featured at the Monday evening moonlight excursion in New Orleans, at the end of the first day of Fall Meeting technical sessions.

"Steamboatin' Down the Mississippi" is the name given to this social function which will start at 6 p.m. at the foot of Canal Street. There Fall Meeting guests will board the steamer President, which has been reserved exclusively for them and this affair.

A Dixieland band will play during the boarding of the steamer, as colorful, New Orleans-famed shuffle tap dancers entertain. On board, a New Orleans French cuisine buffet dinner will be served, featuring lobsters, shrimp, and French pastry. The buffet dinner will be catered by Lefants.

The steamer President has three decks—for dancing, eating, and sitting to enjoy the sights of the 30-mile boat trip. The dancing deck is spacious, and a Dixieland band that plays nightly on Bourbon Street will provide the music. Roving entertainers will perform for those who prefer to relax and view the Mississippi.

"Steamboatin' Down the Mississippi" will be a gay, informal affair—one which could be staged only in New Orleans. The Tuesday evening dinner-dance will be slightly more formal, for the men will wear dark suits or tuxedos and the ladies will wear evening or cocktail dresses. But this function will have the carefree atmosphere characteristic of the annual dinner-dance.

Dinner will be served from 7 to 8:30 p.m., while roving entertainers are performing. Then from 8:30 to 12:30, dancing and the floor show will take place. Guests will have the opportunity of dancing to the music of two outstanding New Orleans orchestras, for there will be one in each of the two ballrooms which have been reserved to accommodate the crowd.

Rene' Lauapre and his 12-piece orchestra will play in the beautiful new International Room. Russ Papalia and his 10-piece band will play simultaneously in the Grand Ballroom. These spacious ballrooms are separated only by a corridor, so guests will be able to enjoy both.

Other entertainment functions are planned for the ladies and discussed on page 51. The men will have luncheons on Monday and Tuesday, the Welcoming Luncheon and the Membership Luncheon.

"Steamboatin' Down the Mississippi," the annual dinner-dance with two orchestras, ladies' activities, men's luncheons, gay Bourbon Street, and historic New Orleans—all of these add up to fun at the Fall Meeting. See you there. R. W. TAYLOR

"Steamboatin' Down the Mississippi," the gay steamboat ride scheduled for Monday night, Oct. 3, will be over at 10:00 p.m. That is just about the time that Bourbon Street comes to life; so if you plan to see the French Quarter on Monday night, you will have plenty of time after "Steamboatin' Down the Mississippi."

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For details, see page 73

ABSTRACTS OF FALL MEETING PAPERS

496-G
The Effect of Fluid Loss on Fracture Extension

(See abstract on page 61)

500-G
Displacement Logging — A New Exploratory Tool

W. M. Campbell and *J. L. Martin*
The Atlantic Refining Co.

A new electric logging method, called displacement logging, often gives a direct indication of the presence of mobile hydrocarbons in hydrocarbon-bearing formations. This method is based on the detection of a bank of connate water which is formed between the invading mud filtrate and virgin formation fluids in these cases. The existence of this phenomenon has been verified by laboratory studies and by actual field logs taken in known oil sands.

501-G
Plunger Lift Correlation Equations and Nomographs

Carrol M. Beeson, University of Southern California

The operation of the 2-in. and 2½-in. expanding cycle-controlled plungers has been placed on a quantitative basis by means of equations obtained from correlations of field data gathered throughout the United States. For each size plunger, three basic correlation equations express the requirement of gas and pressure as functions of size load and depth. A fourth equation gives the maximum production rate in terms of the same variables. Using the equations, nomographs have been constructed to permit graphical solution of the problem of plunger lift performance for a given well. The solution is obtained by plotting the "operating line" for the well, thereby relating the size load to the gross production rate. Examples of use of the nomographs have been included.

502-G
Displacement of Oil by Water — Effect of Wettability, Rate, and Viscosity on Recovery

T. F. Moore and *R. L. Slobod*
The Atlantic Refining Co.

The displacement of oil by water in typical porous media has been studied using new equipment developed to handle flooding experiments on 1-in. core plugs with a precision of about 1 pore per cent. Core described as (1) water-wet, (2) oil-wet, and (3) intermediate wettability are tested. Some definite conclusions are drawn from the study of water-wet and oil-wet cores, their behavior being markedly different. Laboratory floods of water-wet core plugs offer no particular scaling problem, while many scaling factors must be taken into consideration in laboratory oil-wet core flood tests for them to be valid. Additional study is recommended for the case of intermediate wettability.

503-G
Neutron Log Correction Charts for Borehole Conditions and Bed Thickness

J. T. Dewan
Schlumberger Well Surveying Corp.

An experimental setup is described whereby the responses of Neutron Logging instruments have been determined opposite formations of different porosities and under various borehole conditions. The results of these tests are presented in several charts which show how the Neutron Log is affected by the following factors: hole diameter, casing, cement, salinity and weight of drilling mud, and position of logging tool with respect to the wall of the hole. The responses in the case of empty holes are also shown. Charts are furthermore presented which show the shapes of the Neutron Log, as a function of logging speed and time constant, at the boundaries between two formations with different porosities.

505-G
Effect of Mud Column Pressure on Drilling Rates

A. S. Murray, Imperial Oil Ltd. of Canada, and
R. A. Cunningham, Hughes Tool Co.

If a dense fluid such as mud or water is used for circulation, the formation drilled is influenced by a hydrostatic pressure. This pressure depends on hole depth and drilling fluid density. Laboratory tests indicate that drilling rates in many formations are decreased with increased pressure—in some cases as much as 90 per cent. A comparison between laboratory and field tests indicate that drilling fluid head affects drilling rates in the field approximately the same as in the laboratory. Drilling rates of many formations are increased by reducing drilling fluid head.

506-G
An Engineering Appraisal of Small Diameter Hole Drilling in Soft Rock Operations

J. H. Faulk, The Atlantic Refining Co.

The factors influencing drilling rate and bit life in various diameter holes are studied. In soft rock drilling, 4¾ to 6¼ in. drill bits can attain substantially the same daily drilling progress as conventional size bits. Smaller hole sizes can be drilled at a reasonably low "hazard of losing the hole"; however the risk is slightly greater than in conventional diameter holes. An engineering analysis is made of the power and hydraulic requirements of several drill string-hole size combinations to test the feasibility of drilling small diameter holes in soft rock areas. Large economies in rig power requirements appear possible by using smaller size holes.

507-G
The Determination of the Water Injection Program for the Delhi Field by Means of the Automatic Multi-Pool Analyzer

O. L. Patterson, Sun Physical Laboratory, and
C. G. O. Dutton and *H. E. Ellis*, Sun Oil Co.

The operation of the automatic multi-pool analyzer in determining the water injection program of the Delhi field is described. New features of the analyzer include an automatic material balance analog and a least-squares computer for determination of unknown reservoir properties. Operational procedures are sufficiently simple to allow direct use by reservoir engineers on a routine basis. The rapidity and accuracy with which problems may be solved permit repeated analyses as a check upon reservoir performance.

508-G
A New Material for Deep Well Cementing

Dwight K. Smith, Halliburton Oil Well Cementing Co.

A new pozzolanic composition has been developed for cementing oil wells where moderate to high temperatures prevail. At present it is not recommended for use at temperatures less than 140°, and it can be used in wells from 6,000 to 18,000 or more feet where temperature conditions are similar to those along the Gulf Coast. Slurry weights vary slightly according to specific gravity and water requirements of the pozzolan. Materials covered in this paper mix from 13.5 to 14.3 lbs/gal, and have a WOC time comparable to other materials under the same conditions. Economically speaking, this composition is less expensive than either portland cements or retarded cements presently being used under deep well conditions.

509-G
A Flowmeter for Measuring Subsurface Flow Rates

J. L. Newman, H. L. Sauder, and *Courtney Waddell*,
Lane-Wells Co.

A self-contained instrument run on piano wire line and capable of measuring subsurface flow rates is described. An impeller suspended between two torsion wires is subjected to the flow stream. The impeller is symmetrical and indicates direction as well as rate of flow. Changes in instrument sensitivity are accomplished by the use of torsion wires of different diameters. A collapsible type of fluid trap contacts the casing or wellbore and diverts the flow through the flow tube. Successful flow profiles have been made on injection wells with flow rates ranging from 60 B/D to 4000 B/D at surface pressures up to 2000 psi.

510-G
Influence of Rock and Fluid Properties on Immiscible Fluid Flow Behavior in Porous Media

F. E. Merliss, Jr., J. D. Doane, and *M. J. Rzasa*
Cities Service Research and Development Co.

An investigation of immiscible flow behavior in porous material as affected by fluid properties and the solid material characteristics has been made on consolidated and unconsolidated sands. An approximate method of determination of relative permeabilities from external drive experimental data has been derived to correlate the variations encountered in flow behavior. Capillary phenomena were investigated to determine their effect on flow behavior in various wettability systems.

511-G
Wettability Versus Displacement in Water Flooding in Unconsolidated Sand Columns

Jack Newcombe, John McGhee, and *M. J. Rzasa*
Cities Service Research and Development Co.

A series of water floods was made on laboratory prepared unconsolidated sand columns to study the effects on oil recovery of the solid-water-oil contact angle, the oil-water interfacial tension, flood rate, and oil viscosity. For both oil-wet and water-wet systems and a low viscosity oil, recoveries were functions of the oil-water interfacial tension; also, increase in flood rate resulted in increased oil recoveries. High interfacial tension floods were more efficient than low interfacial tension floods on water-wet systems, while low interfacial tension floods were more efficient on oil-wet systems. Intermediate or neutral wettability systems were less sensitive to rate of flood advance and interfacial tension than either oil-wet or water-wet systems.

512-G
Industry Attitudes Toward Slim Hole Drilling

Philip L. McLaughlin, Cardwell Manufacturing Co.

From a technical and economic standpoint slim hole drilling promises to reduce drilling and completion costs. It may also result in reduced workover costs. From the standpoint of industry acceptance, slim hole drilling does not fare so well. Producers, generally, have not accepted slim hole completion techniques for field development. Contractors, generally, have been dissatisfied with profits. A mail survey indicates a need for additional information. Suggestions are given for improving the slim hole picture.

513-G
A Practical Method for Treating Oilfield Interference in Water-Drive Reservoirs

Mohamed Mortada, Magnolia Petroleum Co.

A practical analytical method is developed which provides the practicing reservoir engineer with a handy method of analyzing oilfield interference problems. The procedure employed entails the principle of superposition of individual effects. A set of charts has been developed and can be used to evaluate the individual effects. The charts represent nonsteady-state pressure distribution in an extensive aquifer due to a constant rate of production from an oilfield which can be approximated by circular geometry. By virtue of the method of images, the charts can be used also to treat the case of production near a fault. In addition, provisions are made for treating oilfields which are produced by partial water-drive.

514-G
Design of Casing Strings

C. N. Bowers, Gulf Research and Development Co.

Considerable economy can be effected by designing each casing string individually for the particular set of conditions involved. The paper discusses methods and procedures for incorporating all of the important variables in the design of individual strings; step by step examples are given. A practical method of designing casing strings to provide both tensile strength and collapse resistance at the time each is needed is presented. Strings designed by this method will be much cheaper than those selected from charts or designed by the usual computation methods. This economy is realized along with adequate safety.

515-G
Removal of Sulfides from Brine by Aeration With Exhaust Gas from Submerged Combustion

W. J. Hart and *R. G. Wingate*
Gulf Oil Corp.

Proposed water flooding of the Yates formation in the North Ward-Estes field is expected to require injection of some 150,000 BWPD. Only 500 ppm hydrogen sulfide water is available, and this must be treated. Chemical treatment alone proved uneconomical; however data obtained from a scale model showed that removal of hydrogen sulfide by aeration with exhaust gases, supplied by a submerged combustion unit, combined with chemical treatment merited further investigation and construction of a larger treating plant. A pilot plant capable of processing 7,500 B/D was found economically feasible and adequate for treating purposes.

516-G
New Developments in the Control of Lost Circulation

P. P. Scott, Jr., and *J. L. Lummus*
Stanolind Oil & Gas Co.

Laboratory and field tests were conducted for the purpose of improving techniques for the control of loss of circulation of drilling fluids and to determine some effects of lost circulation materials on drilling fluids and drilling rates. Physical properties of granular materials most suited for use in drilling fluids were found. These granular materials were found to improve the lubricity of drilling fluids and not impair the cutting action of rotary rock bits. Results of field tests show that a slurry of diesel oil-bentonite-cement will plug severe lost circulation zones containing natural fractures and vugs.

517-G
The Determination of Partial Pressure Maintenance Performance by Laboratory Flow Tests

F. F. Craig, Jr., and *T. M. Geffen*
Stanolind Oil and Gas Co.

Laboratory model flow tests have been made to simulate field conditions of partial pressure maintenance by dispersed gas drive on rocks having sandstone type porosity. A means of calculating relative permeability characteristics from partial pressure maintenance flow tests has been developed. The production performance of a hypothetical reservoir has been calculated for several different injection programs, involving both full and partial pressure maintenance. Results indicate that the maximum oil recovery by these gas injection programs is obtained by full pressure maintenance at the original bubble point. Correspondingly lower oil recoveries are realized by postponing gas injection and/or by reducing the degree of pressure maintenance.

518-G
A Comparison of Field K_g/K_o Characteristics and Laboratory K_g/K_o Test Results Measured by a New Simplified Method

W. W. Owens, D. R. Parrish, and *W. E. Lamoreaux*
Stanolind Oil and Gas Co.

This investigation dealt primarily with the development of a simplified unsteady-state (gas drive) laboratory test method for measuring k_g/k_o relationships of small core samples. In comparison with other presently used testing methods, the gas drive method requires considerably less apparatus, is less time consuming, and is more readily adaptable to a routine type core test. Results obtained by this method on a group of cores from a small depletion drive Oklahoma field, when compared to field performance data, showed acceptable agreement when the weighted average laboratory data were obtained by assuming that at any given time and reservoir pressure, all strata of the reservoir produced at the same GOR.

519-G
Problems in Casing Collapse

G. N. Murchey, Creole Petroleum Corp.

The principal cause of casing collapse in the Bolivar Coast field is compaction of the Miocene producing section and the resultant subsidence of the overlying sediments. The problems discussed concern methods of repairing wells with damaged casing as well as preventive measures being taken or proposed for new wells and workovers. Preventive measures are discussed both for wells completed in the compaction zone and those completed in sands below the compaction zone. Illustrations of the various methods of combating collapse are presented.

520-G
Performance Calculations for Combination Drive Reservoirs

L. D. Wooddy, Jr., and *Robert Moscrip III*
Humble Oil & Refining Co.

A simultaneous solution of the volumetric balance and the unsteady state equation has been used for several years to make performance calculations for combination drive reservoirs. A knowledge of the fluid saturation distribution in the reservoir at various stages of depletion is important for the determination of the efficiency of gas and water as oil-displacement media and, therefore, for the reliable prediction of ultimate oil recovery. To provide this knowledge, the displacement equations are solved simultaneously with the volumetric balance and unsteady state equations. The described calculation procedure has been used satisfactorily to analyze the past performance and to predict the future behavior of combination drive reservoirs under both primary and pressure-maintenance operations.

521-G
Recovery of Oil by Condensing Gas Drive

H. L. Stone and *J. S. Crump*
Humble Oil & Refining Co.

Laboratory studies show that displacement of oil from a reservoir by means of a condensing gas drive approaches 100 per cent under favorable conditions. A condensing gas drive is defined as a gas drive in which the gas utilized is appreciably soluble in the oil it is displacing. The experimental results indicate that the more soluble a gas is in the oil to be displaced, the more efficient the gas is as a displacing fluid. Oil recovery was appreciably enhanced by solubility of the displacing gas in experiments using both light, volatile crude and a heavy, asphaltic crude as the in-place oil.

522-G
An Accelerated Squeeze-Cementing Technique

G. K. Dumbauld, D. Perry, G. W. Binkley, and *F. A. Brooks, Jr.*
Humble Oil and Refining Co.

A new cementing technique has been developed which is particularly applicable to permanent-type well completion operations. The technique makes use of the accelerating effect of calcium chloride on setting time and strength development of cement cake deposited in squeeze cementing. A unique feature is that the accelerator is applied after the unaccelerated cement slurry has been squeezed and the excess has been reversed from the well. Laboratory data and an explanation of laboratory tests are given. The acceleration procedure has been used successfully in field operations.

523-G
Spectral Gamma-Ray Logging

H. R. Brannon, Jr., and *J. S. Osoba*
Humble Oil & Refining Co.

The introduction of the scintillation counter into the field use for gamma-ray well logging has provided a new tool with special utility for the determination of natural radioactivity of sediments. Previous sub-surface gamma-ray measurements have indicated only the total amount of radioactivity of the sediments. With the scintillation counter, the relative amounts of the elements which emit gamma radiation can be determined. Sediments logged included 35 zones in wells located in the Texas Gulf Coast, East Texas, and West Texas. Variations in relative proportions of potassium, uranium, and thorium were noted. Judging from limited data, it appears likely that spectral measurements will yield valuable geological information.

524-G
Analysis of Low-Temperature Separation Plants

H. E. Stamm, III, and *D. G. McCarty*
Humble Oil and Refining Co.

A method for calculating the performance of low-temperature separation plants is discussed, and comparisons of calculated recoveries with those observed during field testing of an installation are shown. The ability to calculate plant performance is valuable as a variety of possible operating programs can be investigated at little cost. The close agreement between calculated and observed plant recoveries suggests that with reasonable diligence plant performance can be calculated within generally accepted engineering accuracy. However, as overenthusiastic employment of calculations can lead to serious error, calculated results should be supplemented with sufficient field or laboratory test data to provide adequate experimental verification.

525-G
Lost Circulation Information Obtained With a New Tool for Detecting Zones of Loss

T. Bardeen, and *A. J. Teplitz*
Gulf Research & Development Co.

A newly developed tool is capable of determining positions of the limits of lost circulation zones with an accuracy of about six inches. Operation of the instrument is not hampered by the presence of sealing materials in the drilling fluid. Information provided by the device permits the selection of the most suitable type of remedial treatment and enhances the effectiveness of the operation by making it possible to apply treatment directly to the zone of loss. Field work with the instrument has also yielded enlightening information on the orientation of fractures involved in pressure-induced losses. Other uses for the device are also contemplated.

526-G
A New Method for Controlling Incompetent Sands

J. K. Henderson, W. L. Sallee and *C. M. Stout*
Dowell Incorporated

A new approach to the persistent problem of unconsolidated sands, has been the development and use of plastic coated walnut shells. Laboratory data, supplemented by results from initial field treatments, indicate that this method has furnished satisfactory sand control, without production losses. In fact, in a number of cases, stimulation of production has been obtained. In general, the treatment consists of injecting a graded solid into a producing formation under elevated hydraulic pressure. Advantages of this method include: ease of application; benefits to production; use in dual completion; elimination of costly fishing operations required in removing conventional screens.

527-G
Successful Conditioning of Pacific Ocean Water for Waterflood Injection

J. D. Sudbury, C. F. Knutson, Martin Felsenthal, and *J. O. Lung*
Continental Oil Co.

Abstract not available at press time.

528-G
A Review and Analysis of Equipment for Running Electrical Cables under Pressure

A. C. H. Cooke, Lane-Wells Co., *Cecil B. Greer*, Bowen Co. of Texas, Inc., and *F. L. Scott, Jr.*, The Dia-Log Co.

Developments in permanent well completion techniques have accentuated the need for improved equipment to handle cables under pressure. Existing conventional packoff devices were tested and their dynamic performance established at 200 to 600 psi with electrical conductor cables. A new packoff technique is reported which permits operating stranded cables at moderate running speeds up to pressure as high as 3,000 psi. In higher pressure ranges a new commercial device is reported for running cables against well pressure as high as 6,000 psi. These new developments should improve well completion practices, resulting in improved well productivity and more precise well control.

529-G
Development of Services and Equipment for Small Holes

T. A. Huber, Humble Oil & Refining Co.

Chief objective of drilling a small hole is to reduce the cost of drilling and equipping a well for testing certain objective sands, or to produce from such sands. In the range from 4¾ in. downward, another important objective is the sizing of the producing facility to producing needs. It is estimated that with proper consideration being given to reservoir fluids and reservoir drive mechanisms, small-hole wells should be satisfactory for producing a good percentage of the reservoirs currently developed. Economic aspects, equipment available, and outlook of small-hole drilling are discussed.

530-G
A New Retrievable Wire Line Cementing Tool

Blake M. Caldwell and *George E. Briggs, Jr.*
Welex Jet Services, Inc.

This paper describes a new retrievable wire line cementing tool, its field operation, well applications, well conditions, and performance data. It has been used successfully to eliminate bottom-hole water from an open hole section, to squeeze cement either a complete or partial set of perforations, to squeeze leaky casing shoes, to seal leaky bridging plugs, and to seal channels in the annulus. The tool utilizes gases from the burning of a high energy propellant to expand a rubber packer against either casing or an open hole section. Further expansion of gases shears an aluminum retaining plug from the bottom of the cement container, forcing cement into the desired position.

531-G
Friction Loss of Fracturing Fluids

Thomas A. Matthews II and *C. O. Bundrant*
The Western Co.

It is desirable to know the pressure losses due to friction while pumping thickened fluids used for fracturing work, in order that injection pressure might be known. Past attempts to calculate pressure drop of emulsions and gels has failed because their viscosity apparently drops off sharply with an increase in shear rate, so that calculations based on laboratory viscosities usually give unrealistically high friction losses. The relationship between shear rate and viscosity was thoroughly investigated and is reported in this paper.

532-G
Effect of Clay and Water Salinity on Electrochemical Behavior of Reservoir Rocks

H. J. Hill and *J. D. Milburn*
Shell Oil Co.

This paper presents the results of an experimental investigation to determine if useful relations could be established between clay content, electrochemical potential, and variation of formation resistivity factor with resistivity of saturating solution. An empirical equation has been developed which quantitatively relates formation resistivity factor to saturating solution resistivity, porosity, and "effective clay content." This relation is indicated to be uniformly applicable to clean or shaly reservoir rocks. Some implications regarding theory and electric log interpretation of shaly sands are discussed.

533-G
Some Aspects of Sand-Oil Fracturing in Long Heterogeneous Sand Sections

Lejuene Wilson, International Petroleum Co., Ltd.

Major results of 319 sand-oil fracturing jobs on the northwestern coast of Peru are discussed. Seventy per cent were successful. Beneficial effects are divided into three categories: induced fractures, elimination of well damage, and opening new reservoirs. General conclusions are that fracturing was successful in wells where as much as 75 per cent of the exposed formation was shale in old, apparently depleted wells, and that opening new reservoirs plus the elimination of well damage were important factors in the successes.

534-G
An Analog Computer for Studying Heat Transfer During a Thermal Recovery Process

L. C. Vogel and *R. F. Kreuger*
Union Oil Co. of California

A design is presented for an electrical analog computer which can solve non-steady state heat conduction problems in an extensive radial formation containing a moving cylindrical source. The computer is used to simulate a simplified thermal oil recovery process in which heat transfer from a moving constant temperature source takes place radially by conduction only. Temperature distribution curves are shown for several different assumed modes of travel for the heat source. The data are used to estimate the residual fuel requirements necessary to maintain a self-propagating isothermal front for the particular system being studied. It is believed use of this computer will aid in evaluating the economic feasibility of oil recovery by various thermal processes.

535-G
Gas Drive and Gravity Drainage Analysis for Pressure Maintenance Operations

D. R. Shreve and *L. W. Welch, Jr.*
The Carter Oil Co.

An analysis for predicting the behavior of reservoirs exploited by a combined gas drive and gravity drainage mechanism is presented. The method allows the prediction of gas-oil ratio, oil production rate, and cumulative oil recovery for high relief pools in which pressure is maintained by gas injection. The reservoir is represented by a model of communicating vertical prisms, with production or injection at the upper or lower boundaries of each prism. The theory of gravitational segregation of two fluids within a reservoir is discussed for all saturation ranges. A description of an application of the analysis to a typical field problem is also presented.

536-G
Mechanism of Waterflooding in the Presence of Free Gas

J. R. Kyte, R. J. Stanclift, S. C. Stephan, and *L. A. Rapoport*, The Carter Oil Co.

Experimental studies covering a wide range of core materials and fluid properties have been conducted to determine the mechanism of oil displacement by water in a partially gas-saturated porous medium. In all instances, the presence of a gas phase was found to have beneficial effect in reducing residual oil saturations. The practical significance of this benefit is discussed, and a simplified procedure is outlined for evaluating the effects of free gas on water flooding by means of short core tests.

537-G
Application of the Gelatin Model for Studying Mobility Ratio Effects

Paul B. Crawford and *Melven B. Burton*
Texas Petroleum Research Committee

A procedure is given which describes how the gelatin model may be used to study the effect of mobility ratio on areas swept before and after breakthrough in fluid injection programs. Difference in mobility ratio are achieved through the proper selection of electrolytes for the invading and displaced fluids. The progress of the front is followed visually and photographed or traced into plates at desired positions before and after breakthrough. Example applications to standard flooding patterns, vertically and horizontally fractured reservoirs, and the in-situ combustion recovery process are presented.

538-G
Effect of Pressure, Temperature, and Wellstream Composition on the Quantity of Separator Fluid

W. E. Portman and *John M. Campbell*
University of Oklahoma

The economics surrounding separation and storage of oil and condensate has become increasingly important. This discussion summarizes the results obtained during a preliminary investigation of the variables affecting the quantity of liquid separated from a given wellstream. The approach has been largely statistical in order to evaluate the relative effect of the variables. A series of correlating charts have been prepared to enable the field engineer to predict the amount of stable stock liquid present in the first stage separator. The charts are particularly convenient for estimating the relative effect of temperature and pressure in economic studies.

539-G
Theory of Dimensionally Scaled Models of Petroleum Reservoirs

G. A. Croes, J. Geertsma, and *N. Schwarz*
Koninklijke/Shell Laboratorium

The dimensionless groups, to which the variables that govern the displacement of oil from reservoirs by liquids can be combined, are derived. Three types of displacement are considered, viz., cold-water drive, hot-water drive, and solvent injection. The physical meanings of the groups are discussed. They are brought together on a chart, from which their mutual relation and their correspondence to related dimensionless groups in common use in other engineering sciences can be read off. The limitations of dimensionally scaled model experiments as a useful tool for studying liquid flow in porous media, as occurring in oil reservoirs, are discussed.

540-G
Development and Testing of Jet Pump Pellet Impact Drill Bits

J. E. Eckel, F. H. Deily, and *L. W. Ledgerwood, Jr.*
The Carter Oil Co.

A new method for drilling the earth's formations has undergone extensive laboratory and shallow earth drilling experimentation. This method, pellet impact drilling, uses the energy of a large mass of high velocity steel spheres to break and crush the rock. Pellets are confined to a region close to the bottom hole. Motive fluid for transporting and recycling the pellets is supplied by a modified jet pump. The experimental laboratory work and analytical procedures necessary for the design of a pellet bit are described. Drilling performance in representative rocks, hydraulic operating characteristics, and metallurgical problems are discussed.

541-G
Northeast Butterly Pool — Case History

S. D. McCloud, Jack Marshall, and *Roy Butler*
Continental Oil Co.

In producing the Northeast Butterly pool crude oil, it was necessary to pump sand consolidating agents into the formation, treat with large amounts of emulsion breaker, blend with high gravity crude, heat in the stock tanks as well as the heaters, and blend additionally as the oil entered the pipeline. Steam jets and drains installed in heaters and two trucks equipped with sand buckets, working 24 hours a day, were necessary to separate the produced sand from the oil and remove it from the area. Despite these problems, over 2,500,000 bbl of oil have been produced in less than 10 years from a reservoir containing 185 surface acres.

542-G
Experimental Waterflooding Recoveries at Pressures Above and Below the Bubble Point

D. M. Bass, Jr., and *Paul B. Crawford*
Texas Petroleum Research Committee

Laboratory investigations have been made of the effect of fluid characteristics, variations in gas saturation, water saturation, and water injection rate on the oil recovered by water flooding. Oil recovery efficiency by a combination of solution gas drive and water injection is shown to be sensitive to the time (pressure) at which water injection is initiated. The time (pressure) at which optimum saturation conditions exist is shown to be a function of the physical characteristics of the reservoir fluid. Waterflooding efficiency, as obtained in the laboratory, is shown to be sensitive to the rate of water injection when there is a free gas phase in the core.

544-G
Simultaneous Flow of Liquid and Gas Through Horizontal Pipe

A. F. Bertuzzi, M. R. Tek, and *F. H. Poettmann*
Phillips Petroleum Co.

A method is presented for predicting pressure drop for two-phase fluid flow in horizontal pipes. Advantages of the new method are explained, and it is presented in a simplified graphical form suitable for field use. A two-phase f factor is defined and correlated with parameters involving the flowing gas-liquid mass ratio, a Reynolds number for the gas phase, and a Reynolds number for the liquid phase. The choice of parameters allows the correlation to reduce to the usual f factor plot for the limiting conditions of all gas or all liquids.

545-G
Determining Gravity Drainage Characteristics on the Centrifuge

J. W. Marx, Phillips Petroleum Co.

A method is given for predicting the complete gravity drainage characteristics of arbitrarily long columns from centrifuge drainage measurements on reconstituted core samples. Oil residuals corresponding to hundreds of years of normal gravity depletion can be obtained in a few hours on the centrifuge. The gravity flow rate at any stage of the depletion process may be determined from the time correlation derived, and experimentally checked, in this study.

551-G
The Near-Term Supply and Demand Outlook for the Petroleum Industry

John G. Winger, Chase Manhattan Bank

This paper is in two parts. The first will deal with the current statistical position of the petroleum industry and the supply and demand outlook for the remainder of 1955 and the year 1956. Supporting the conclusions reached will be an explanation of forecasting techniques used. The second portion is a discussion of several economic factors operating in the direction of chronic oversupply for the industry. Brought into focus is the impact of these elements on postwar developments and their probable effect in the near-term future.

552-G
Objectives of Engineering Education

W. V. Houston, Rice Institute

The expansion of engineering in recent years has put severe demands on all sides of an engineer's proficiency. An engineering project must bring together engineering experience, management skills, economic and business judgment, technical skill and knowledge, and scientific understanding of the most profound nature. The university cannot give a prospective engineer experience in all of these fields, or completely adequate experience in any one. The proper function of a university is to provide the general education and the scientific background against which an engineer can place his experience.

557-G
Flow Properties of Suspensions in Drilling Mud Design

W. C. Browning, Marathon Corp.

The colloid chemical aspects of the flow of suspensions, the function and use of dispersing agents and their effect on the flow properties of aqueous drilling muds is given in this paper. Among the factors to be considered in the design of oil well drilling fluids are the controlled deflocculation of the various suspended solids to maintain desired flow conditions, the prevention of osmotic swelling of bentonitic shale drilling chips, and the prevention of swelling in situ of formation and reservoir clays. Control of swelling can be effected by aqueous media containing suitable concentrations of alkaline earth ions or sodium chloride. The use of dispersing agents that can function as effective deflocculents in neutral pH, alkaline earth ion, or sodium chloride media is essential in the design of inert aqueous drilling fluids.

496-G
The Effect of Fluid Loss on Fracture Extension

J. G. Davis, J. J. Reynolds, and *H. F. Coffer*
Continental Oil Co.

Field trials have definitely shown that superior fracturing treatments are obtained when a low fluid loss oil is employed as the sand carrier. Such a carrier may now be made very economically from lease crude oil by the use of a fluid loss controlling additive. Through fluid loss control fewer sand-outs are encountered and production increases are more sustained. The converted oils have performed excellently in formations that have been very difficult to fracture in the past. Both laboratory and field results have shown the fluid loss additive to be fully compatible with the various gelling materials now available. Field tests are explained which demonstrate the effectiveness of low fluid loss in fracture extensions.

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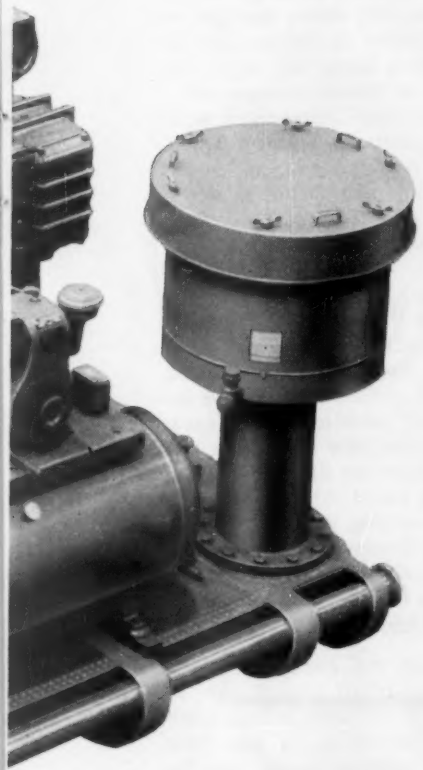

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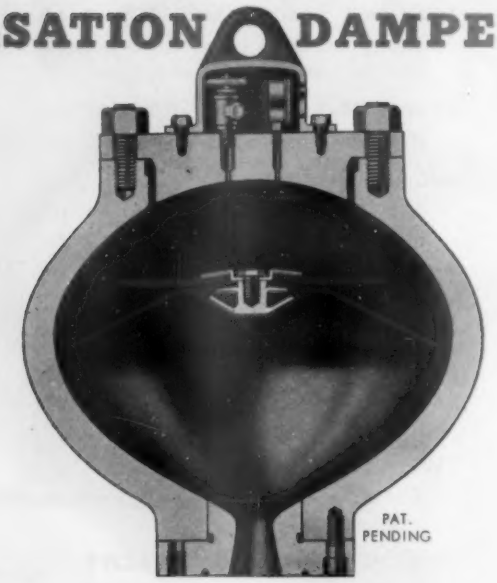

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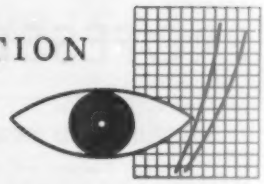

JOHN R. McMILLAN*
MEMBER AIME

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AIME MEMBERSHIP — and YOUR ADVANCEMENT to a MANAGEMENT POSITION

"How can membership in the AIME help a young man toward a management career?" To really be frank in answering this question, I must admit that it cannot help you unless you want to help yourself. But I feel that you cannot be truly valuable to your company as an engineer unless you are a member of the Petroleum Branch, attend its technical meetings, and join in its field trips and social gatherings.

Management looks for many things when they study their engineering personnel for advancement. They look for ability, accuracy, truth, initiative, personality, self-reliance, loyalty, and courage. They want to know if the technical man joins in and contributes to his profession, for the man who respects his profession also respects his professional society and takes part in the activities of it.

Thirty per cent of the members of the Petroleum Branch are acting in management capacity, in the categories of company executives, chief engineers, production superintendents, drilling executives, and service company executives. In helping these men to attain management positions, AIME has offered: (1) contact and association with professional men, (2) opportunity to keep up with the technology of the profession, (3) development of a broad point of view in respect to the various fields of petroleum engineering, and (4) an opportunity for personal contribution, with the prestige and self-satisfaction which this brings.

Petroleum Transactions

Fundamentally, any meeting of the Petroleum Branch of AIME is a forum — a place where we come to listen and discuss the problems at hand. It may deal with any of a multitude of petroleum engineering subjects; name anything and somewhere we have discussed it and probably recorded it.

In *Petroleum Transactions,* the comprehensive record of petroleum engineering, you will find recorded the initial technical papers that deal with the basic theories underlying many of the items we accept as routine today. The first paper dealing with the theoretical decline in reservoir pressure as related to the production of oil and gas by Coleman, Wilde and Moore was published in 1929 — a paper which led the way to the material balance and productivity index calculations as we now understand them. You can follow the development through our literature of core analyses, electric logging, cycling operations, slim-hole drilling, oil base muds, and multitudinous other processes from the laboratory to the production tank.

Theoretical to Practical

Things that we published years ago and were considered long-hair type articles — too technical for the practical field petroleum engineer — are now a part of his daily vocabulary. Without batting an eye, we now talk about such things as shrinkage factors, viscosities, water loss, bottom-hole pressures, relative permeability, productivity indices, gas depletion, gas cap and water drive. Truly the things that are being written in the *Transactions* today are just as important and also sometimes just as dry and uninteresting as those old articles were; but those technical papers become priceless when you want to do research on some knotty problem that causes you to do a little brushing up on your engineering reasoning powers.

Then there is the less technical side to the Petroleum Branch. Through Local Sections many unofficial functions are given in the form of barbecues, field trips, dances, "fellowship hours," etc. By attending these functions, in addition to your regular meetings, you will get to know your fellow competitor, to exchange ideas with him in a friendly atmosphere and in doing so you will develop your own personality and power of expression. The development of your ability to transmit and exchange ideas with others will aid you in selling your recommendations and ideas to your management. It will also improve your relationship with your fellow employees.

Outlook of the Manager

If you can develop the ability to sell your ideas to capital and capital accepts them and profits thereby, you are then no longer a worker. Look out! They will make you a manager.

Seriously, in *Harvard Business Review* McMurray says, "If an individual is inherently passive, dependent and submissive—no formal training, no advanced management courses at a university, and no spirited harangues by his superiors are going to change him."

The important thing, however, is for each petroleum engineer to decide in his own manner whether he wants to be a manager or not—to find the place where his particular personality and ability does the greatest good, where he himself is satisfied and content with his progress and accomplishments.

Whatever his path—be it introvert or extrovert—I am certain that he will gain character and professional pride from his association with the Petroleum Branch. ★★★

*John R. McMillan, 1954 Petroleum Branch Chairman, is executive vice-president of Monterey Oil Co.

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☆ Petroleum Engineer with six years' intensive experience in Arkansas, Louisiana, and Texas, desires position with opportunity for advancement. Graduate of 1949, married, two children. Now employed, and responsible for drilling, workovers, production, and waterflood project for independent. Code 256.

☆ Graduate Petroleum Engineer, age 32, married. Ten years' extensive experience in rotary and cable tool drilling, primary and secondary recovery production techniques, and administrative work for major and independent firms. Desires a responsible position anywhere in Continental North America with an aggressive organization. All offers acknowledged. Code 257.

☆ Registered Chemical Engineer, 43, married, two children. Ten years in drilling mud and fluid flow research. Background of physical metallurgy and physical and non-destructive testing and inspection. Looking for an opportunity to combine oilfield, research, and metallurgical experience. West Coast preferred. Now employed. Code 258.

☆ Experienced waterflood engineer capable of evaluating, developing, and managing flood properties desires position with aggressive independent. Has Oklahoma professional engineer registration. Code 259.

☆ Petroleum Engineer with five years' experience as construction and production engineer seeks position with small company, independent, or service company. Now employed by major company. Will locate anywhere, 29, married, veteran, two children. Code 260.

☆ Reservoir Engineer and Logging Expert, 35, married, with seven years' experience in field engineering and all phases of reservoir engineering with one major company. Currently employed as reservoir engineer in a key position. Desires responsible staff position with opportunity for advancement. Code 261.

☆ Petroleum Engineer, BS degree, 27, single. Three years' practical experience in drilling and two years as a production engineer with experience in workovers and well completions. Currently employed with major company. Desires staff position with smaller organization in South Texas. Code 262.

☆ Registered Petroleum Engineer. Experience consists of three years' drilling and production, 10 years' reservoir engineering, valuations, secondary recovery, oil and gas reserves, unitization, and regulatory commission work in supervisory assignment; Northwest Texas. Desire employment with Independent. Present salary $12,000. Code 263.

(Continued on Page 68)

PETROLEUM ENGINEERS WANTED FOR VENEZUELA & COLUMBIA

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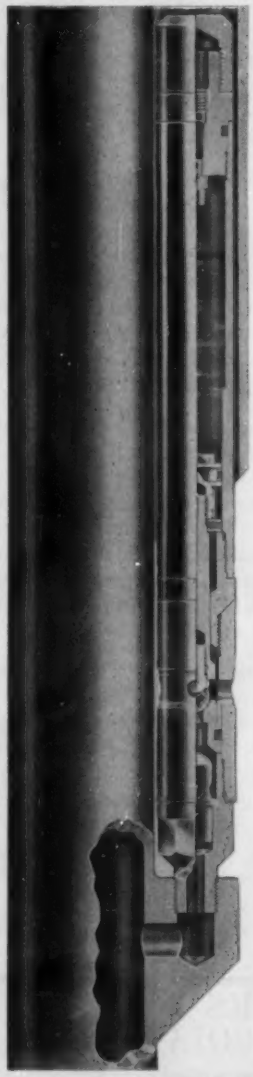
HUGOTON SECTION ELECTS KENDALL

E. C. Kendall, Chemical Process Co., has been elevated to first vice-chairman of the Hugoton Local Section. John D. Ford of Panhandle Eastern Pipeline Co., Liberal, Kan., was elected second vice-chairman for the remainder of the year. George W. Atchley, former first vice-chairman, has been transferred to Dallas by the Republic Natural Gas Co.

During the summer, this section has held two meetings. William Warner of Natural Gas Pipeline Co. of America discussed "Compression" at the May meeting. He talked on the fundamentals and operating problems encountered in the compression of natural gas. In June Pat Massey and William Horton, representatives of Camco Gas Lift Co., discussed "Siphon Operation in Gas Wells."

Carl A. Young Dies

Carl A. Young, director of the Production Div. of the American Petroleum Institute for many years, died on Aug. 30 in Dallas. He had been an AIME member since 1936.



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Caracas, Venezuela, Ph. 57.092.

Employment Notices

(Continued from Page 67)

POSITIONS OPEN

☆ Research mathematician or theoretical physicist. Major oil company research laboratory has opening for PhD or MS in the field of reservoir engineering research. Previous experience in applied mathematical research desirable but not necessary. Excellent working environment with opportunities for advancement. Replies confidential. Send detailed education and experience record, age, and state salary expected. Code 590.

☆ Major independent has an opening for a petroleum engineer trainee. No previous experience necessary. Good working conditions with excellent opportunities for advancement. Replies will be considered confidential. Send detailed educational and experience record with small photo attached, state age and starting salary expected. Code 591.

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MEET the AUTHORS

A. J. TEPLITZ was graduated from the University of Kansas with a BS in chemical engineering. After working with Continental Oil Co., he accepted a Gulf Fellowship at Mellon Institute and at the same time engaged in graduate studies at the University of Pittsburgh. Now he is assistant director of the Production Engineering Div. of Gulf Research & Development, having joined the company in 1935.

EUGENE M. POHORILES is a petroleum engineer in the Production Engineering Div. of Gulf Research & Development Co. He holds a BS degree from Oklahoma A&M and a MS degree in petroleum engineering from the University of Pittsburgh. The former Stanolind Oil & Gas Co. employee is on the executive committee of the Pittsburgh Petroleum Sub-section of AIME.

JOHN K. RODGERS is a research engineer in the Reservoir Mechanics Div. of Gulf Research & Development Co. He attended Carnegie Institute of Technology, majoring in chemistry. Later he joined Gulf's Petroleum Production Fellowship of the Mellon Institute in 1929 and has been engaged in their drilling and production problems since that time.

MURRAY F. HAWKINS, JR., is professor of petroleum engineering at Louisiana State University, having been at LSU since 1946. He holds a BS degree in physical chemistry and a MS degree in physics. He has been employed by Carter Oil Co., U.S. Navy Department, and the Ethyl Corp.

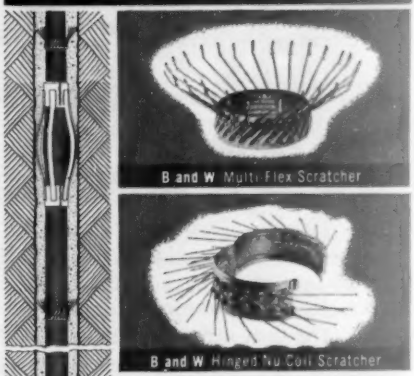
W. J. AINSWORTH is now a lieutenant in the Corps of Engineers. He is a June, 1954, graduate of Louisiana State University in petroleum engineering. After working with Magnolia Petroleum Co. until May,

(Continued on Page 72)

CORRECTION

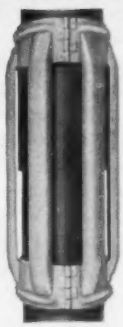
In publishing the paper "The Effect of the Relative Permeability Ratio, the Oil Gravity, and the Solution Gas-Oil Ratio on the Primary Recovery from a Depletion Type Reservoir" in the August issue of JOURNAL OF PETROLEUM TECHNOLOGY, the abscissa was inadvertently deleted from Figs. 6 through 11. In each of these figures the abscissa should have appeared "Recovery in Stock Tank Barrels as Fraction of Total Pore Volume." Better reproduction of these same figures has been accomplished in a subsequent printing, and reprints containing this improved reproduction and abscissas as they should have appeared originally can be obtained free of charge from the Petroleum Branch office.

B and W
SCRATCHERS AND CENTRALIZERS



B and W Multi-Flex Scratcher

B and W Hinged Nu Coil Scratcher


B and W Plain Stabilizer

B and W Latch-on Centralizer with Kon-Kave Bow

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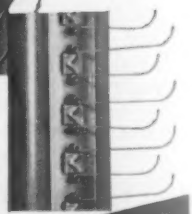
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5404

PERSONALS

O. H. BERRY (left) and CHARLES E. PHILLIPS have announced the formation of Berry and Phillips, a consulting petroleum engineering firm. The firm will specialize in evaluation and management of oil and gas properties from its Midland offices. Berry is formerly manager of production and chief engineer for The Vickers Petroleum Co., Inc., Wichita. Phillips recently resigned the position of consulting petroleum engineer for Robert W. Harrison & Co., Houston. Both men are graduates of Texas A&M and are registered professional engineers.

☆

JOHN H. JENNINGS, manager of the petroleum department of the Colorado National Bank, has been appointed vice-president by the board of directors. Before joining the bank in March, 1954, he was chief evaluation engineer for Deep Rock Oil Co., Tulsa. Prior to that the University of Pittsburgh graduate had been with Sunray Oil Corp., Mountain Fuel Supply Co., and Ohio Oil Co.

☆

W. T. HUDSON has opened an office in Denver as a consulting engineer. He recently resigned as division manager of Ralph Fair, Inc., in Billings.

☆

JAMES F. BELL has been advanced to the position of executive vice-president of the Portland Gas and Coke Co., Portland, Ore. He has been a vice-president since 1949 and a member of the board of directors since 1950, having joined Gasco early in 1946 as assistant to the president. He is a graduate of Stanford University and took five years of postgraduate and research work, including two years of study at the University of Munich.

PAUL ANDREWS, Branch vice-chairman in 1950, has been elected chairman of the Conservation Committee of California Oil Producers. Andrews, of Signal Oil and Gas Co., will serve for a year in this capacity, after having served for nine years as a member of the Conservation Committee. The Conservation Committee conducts a voluntary oil conservation program in the state.

☆

GEORGE C. MCGHEE has announced the opening of an office in the Republic National Bank Building, Dallas. He will engage in exploration for and production of oil and gas, specializing in geophysical evaluation and drilling of prospects as McGhee Production Co. In conjunction with Petroleum Reserves, Inc., he will engage in purchasing of producing oil and gas properties. H. B. RENFRO is his associate in this office.

☆

W. R. JOHNSTON, supervising petroleum engineer for Humble Oil & Refining Co's West Texas Div., has resigned to accept a position with Pacific-Northwest Pipeline Co. He will be manager of production and drilling. Other changes in the Humble organization include: G. L. KEMPE, senior petroleum engineer, has been transferred from the East Texas to the West Texas Div. office: and GALYN D. POWNELL and DAN S. FERGUSON, junior petroleum engineers, have been transferred to the Petroleum Engineering Div. Houston office. Pownell was in the East Texas Div. office and Ferguson was in the Hawkins District prior to this change.

☆

ROGER HENQUET is in charge of a new office opened by D. D. Feldman Oil and Gas in Paris, France. Purpose of the new office will be exploration in Europe and the Middle East. Henquet, a graduate petroleum engineer and geologist, served as executive vice-president and general manager of Schlumberger Well Surveying Corp. for more than six years. He then became manager of European and Middle Eastern operations for The Superior Oil Co. for three years, before forming his own organization in Paris, the Societe' d'Etudes Petrolieres.

R. J. GRANBERRY (left) has been named district manager of Core Laboratories' Upper Gulf Coast operations. He is a member of Core Lab's board of directors and has served as district manager in Corpus Christi for the past eight years. R. C. WILSHUSEN (right) has been promoted to district manager and assigned to the Corpus Christi area. He has served in Oklahoma City as assistant district engineer in the Oklahoma-Kansas area since 1951.

☆

J. P. EVERETT has been appointed petroleum engineer for the Oil and Gas Dept. of The Hibernia National Bank, New Orleans. He leaves a position on the University of Kansas faculty, where he has served for the past four years. In addition to his oilfield experience, Everett holds BS and MS degrees in petroleum engineering from the University of Oklahoma.

☆

JOE W. MALY, Halliburton Oil Well Cementing Co.'s assistant division manager at Oklahoma City, is transferring to Denver to serve in the same capacity as manager of Halliburton's Rocky Mountain division. He will assist OBIE L. STALCUP, Rocky Mountain division manager, and replace J. W. HALL, now on sick leave.

☆

FREDERICK L. CONVERS is now petroleum engineer in the Patent Section of Gulf Research & Development Co., Harmarville, Pa. He left a job as technical writer for a Pittsburgh advertising agency to take this new position. Convers was with Stanolind Oil & Gas Co. as a petroleum engineer for six years, then for three years was in the Petroleum Engineering Dept. of the University of Pittsburgh.

Engineering Education Report 1 on

The CHARACTERIZATION of the PETROLEUM ENGINEER

Editor's Note: The problem of engineering education is becoming more involved and in some cases critical. The Engineering Education Committee of the Petroleum Branch believes that some of these problems should be brought out in the open and discussed. They will present several articles on timely subjects and will welcome any discussion or questions, which they will try to answer. They will also appreciate members contacting the local committeemen whenever convenient.

The Committee is: A. W. Walker, chairman, John C. Calhoun, W. H. Carson, H. H. Power, Benjamin Craft, Clark F. Barb, Frank G. Miller, H. G. Botset, Trent Wood, R. L. Whiting, C. V. Kirkpatrick, L. B. Taylor, Carrol M. Beeson, Charles Dodson, R. C. Earlougher, Douglas Ragland, A. L. Vitter, Jr., Curtis McCarthy, and John E. Sherborne.

Introductory Remarks

This is a most important and timely subject. It is imperative that a distinction be made at the outset between a profession and a job. Just as lawyers as professional men have employment with law firms, so do engineers as professional men have employment with companies. Professionalism is not restricted to private practice, although this is a recognized ultimate goal of many individuals in the engineering profession.

What Is An Engineer?

An engineer is often defined by comparison with a scientist. The scientist creates the tools, and the engineer puts them to work for the practical benefit of society. There are a few scientists who are engineers and some engineers who are scientists. The vast majority of both groups, however, do not fall in the dual category.

The engineer is *not* a technician. He is a creative, professional man and the fruit of his endeavor is a higher standard of living for all. From the theoretical formula of the mathematician, the engineer derives the empirical expression that allows the design and construction of such structures as the Golden Gate Bridge, Boulder Dam, the Empire State Building, the Holland Tunnel, and many others. From the deriviations of the theoretical physicists, the engineer transfers the atomic and hydrogen bombs from paper to a practical reality.

The engineer compounds the knowledge of mathematics, physics, chemistry, and geology to insure that the maximum amount of oil and gas will be obtained from underground reservoirs—reservoirs that may be 3 miles below the earth's surface. He designs equipment that will allow drilling for oil and gas to depths of approximately 4 miles. He designs, selects, and creates systems that will allow the economic production, transportation, and refining of crude oil and gas—crude oil and gas, without which the standard of living, as we know it today, might never have been achieved.

What is the contribution to mankind of theory alone, if it cannot be reduced to application? Aside from certain areas of religious philosophy, artistic, and biological endeavor, my answer is—none whatever! It is the engineer who sees that the theoretical scientist and mathematician does not labor in vain. The engineer is an analytical thinker whose creed is that of practical accomplishment.

What Characterizes a Petroleum Engineer?

The competent professional petroleum engineer is characterized by all of the aforementioned attributes. He is designated as a petroleum engineer because his major engineering effort is directed toward the maximum efficient and economic recovery of oil and gas from the reservoir.

In the overall picture, he must know existing equipment and often has to design new equipment for drilling, producing, and working over wells—as well as surface equipment, which is necessary once the well has been successfully completed.

He must select prime movers, design casing strings, plan drilling fluid programs, combat corrosion, test wells, produce wells, estimate reserves and recoveries, plan pressure maintenance programs, design systems for transporting oil and gas, and reduce operational hazards. All of this must be accomplished within the framework of special physical, legal, and economic considerations peculiar to the petroleum industry.

From the foregoing it is clear that any graduate engineer, whether he be ME, CE, EE, Chem E, or PE, given proper time and training may develop into a competent petroleum engineer. This is true because all good engineers have one common trait—they are analytical thinkers.

Why then, you ask, is petroleum engineering offered as such? The answer is simple but involves essentially three principal considerations:

First, it is axiomatic that an individual can accomplish more if his efforts are directed toward a field of major interest for him. Good baseball players do not like tennis better than baseball.

Second, it will be noted from the above characterization that a petroleum engineer must combine the basic knowledge of all other fields of engineering with that of geology. In other words, he is in the true sense of the expression a "general engineer" with a strong scientific and analytical background. The "general engineer" is one who has all the attributes that *executives* of industry *say* the ideal engineering graduate should have, but one who personnel departments will not hire if he is called a general engineer—so we call him a petroleum engineer.

Third, note that the statement concerning other engineering majors, such as CE, ME, etc., said that these individuals *may* develop into competent petroleum engineers. It is equally true that competent petroleum engineers can and do develop into competent ME's, CE's, Chem E's, etc. The record shows, however, that in many instances increasing numbers of petroleum engineering graduates are moving into responsible supervisory positions more rapidly than engineers of the other major fields. These statistics, however, were compiled 10 to 15 years back.

So this is the character of the petroleum engineer—a professional man qualified through his training to function as a general engineer, to put into oilfield practice the research of the scientist, and to affect maximum efficient and economic recovery of oil from the reservoir.

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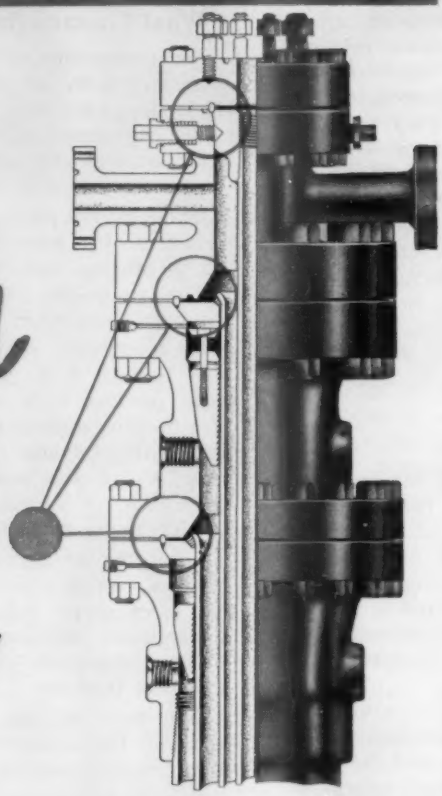

Assembly of Type "RH" Rectorhead Casing Heads with three Casing Strings and Type "M" Tubing Head. Notice how welding ring seats in head body. API Ring Gasket completes the "seal-with-steel."

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RECTORHEAD RECTORSEAL

Meet The Authors

(Continued from Page 69)

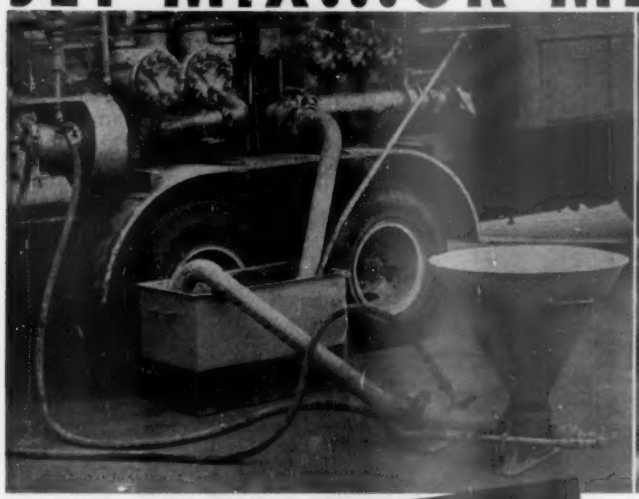
1955, he entered the military service. Earlier, he worked as a roustabout for the Atlantic Refining Co. in Lafayette, La.

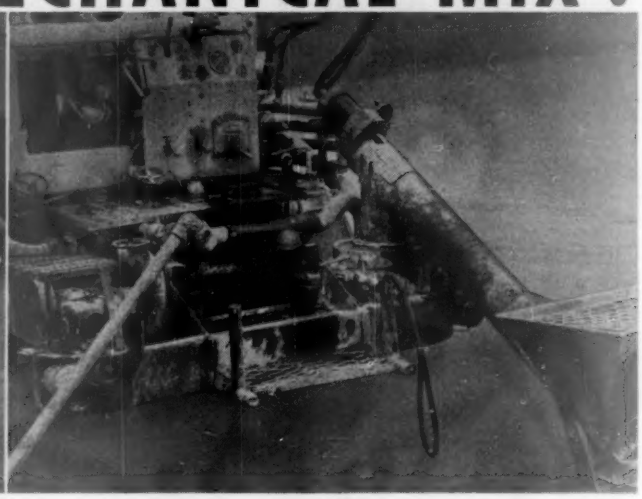
M. H. CULLENDER has been assistant to the chief production engineer of the Phillips Petroleum Co. Natural Gas Dept. since 1950. He joined Phillips in 1939 after receiving his BS degree in mathematics from West Texas State College. His early experience with Phillips was in the Natural Gas and Natural Gasoline Departments.

LEO A. RAPOPORT is senior research engineer of the Research Dept. of Carter Oil Co. He supervises studies of fluid mechanics in the Exploitation Research Section. A graduate of the University of Paris and the National Superior School of Mines of Paris, he joined Carter in 1948 after working as a drilling engineer for the S.N.P.A. in France.

CHARLES C. NATHAN holds a BS degree in chemical engineering from Rice Institute and a PhD in physical chemistry from the University of Pittsburgh. Since 1948 he has been a research chemist for The Texas Co. in the Research Div. of the Producing Dept. He was formerly employed for two years as a chemist and engineer by the Monsanto Chemical Co.

JET MIX...OR MECHANICAL MIX?





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Now working on plans for the Oct. 27-28 AIME Formation Evaluation Symposium are committee chairmen from the Gulf Coast Local Section. Left to right, front row, are T. O. Allen, Humble, general committee; C. V. Kirkpatrick, University of Houston, program chairman; George Gray, Baroid, publications chairman; J. D. Clark, Union Oil Co. of California, general chairman; and L. B. Lipson, University of Houston, arrangements chairman. On the back row are: Guy Johnston, consultant, registration chairman; M. Scott Kraemer, Stanolind, exhibits; R. R. Rieke, Schlumberger, publicity chairman; Mark Krause, Humble, registration chairman; J. R. Welsh, Humble, membership chairman; and R. E. Bush, Lane-Wells, exhibits chairman.

Decker on Committee to Study Building Site

Harold Decker, an AIME vice-president and the president of Houston Oil Co. of Texas, has been named to a Special Task Committee charged with recommending a specific site for the new Engineering Societies Center. Other AIME members of this committee are Clyde Williams, a past president of AIME and now director of Battelle Memorial Institute, and H. DeWitt Smith, AIME president and New York City consulting engineer.

These three AIME representatives will serve as members of a Special Task Committee of 15 persons, composed of three members from each of the five societies. Special Task Committee members are to report to their respective societies no later than Feb. 1, 1956. All five societies have voted to appropriate $15,000 to finance the activities of the Special Task Committee.

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Local Section Membership Contests

ENTERING the HOME STRETCH

VIRGINIA B. DAGGETT | *ASSISTANT SECRETARY PETROLEUM BRANCH, AIME*

The East Texas and Kansas Sections are tied for the lead in Group B of the Petroleum Branch Membership Contest, with Denver Petroleum Section running close behind. These three sections started the year with exactly the same membership. At the end of August, Kansas and East Texas had each secured 19 applications, and 17 had been credited to Denver.

In Group A, the Hugoton Local Section has moved to first place from its fourth-place position at the last report in the May issue. Panhandle, which was leading at last report, follows closely by only two-tenths of a per cent.

Oklahoma City has nudged out the Permian Basin Section for top ranking in Group C. The Gulf Coast Section, with 151 applications, still holds a strong lead in Group D. It is interesting to note that Gulf Coast and Southwest Texas Sections, both of whom conducted intensive local membership drives in the spring and early summer, show a higher percentage increase at this time than the leading sections in Group C, which had smaller initial memberships.

The new Venezuela Petroleum Section appears on the official contest report for the first time, and shows up admirably in second place of Group C with 6.2 per cent increase.

Competition is expected to increase during the last four months of the year, as sections enter their Fall activities. Winning sections in each group will receive prizes after the end of the contest on Dec. 31.

A total of 581 applications for Petroleum Branch membership had been received by Aug. 31. This compares with 552 for the same period last year. However, the lead over last year is diminishing. The increase in applications received over the same period of 1954 was 15.7 per cent at the end of April, 17.3 per cent at the end of June, and now stands at only 5.3 per cent.

The total of applications received in 1954 was 930. For the past three or four years, new applications have been increasing at the rate of about 30 per cent a year. Although some leveling off might be anticipated, it is still entirely possible that 1955 could show an increase of 20 to 30 per cent over 1954.

PETROLEUM BRANCH MEMBERSHIP CONTEST
EIGHT-MONTHS REPORT

Covering Applications Received Jan. 1-Aug. 31, 1955

Section	Jan. 1 Membership	Applications Received	Per Cent Increase
Group A			
1. Hugoton	27	5	18.5
2. Panhandle	60	11	18.3
3. Hobbs	88	15	17.0
4. Billings Petroleum	61	10	16.4
5. Mississippi	59	8	13.6
6. North Texas	84	5	6.0
7. South Plains	51	1	2.0
Group B			
1. Kansas	141	19	13.5
East Texas	141	19	13.5
2. Denver Petroleum	141	17	12.1
3. Wyoming	152	11	7.2
4. Lou-Ark	148	8	5.4
5. Illinois Basin Petroleum	154	7	4.5
6. West Central Texas	135	6	4.4
Group C			
1. Oklahoma City	269	23	8.6
2. Venezuela Petroleum	194	12	6.2
3. Permian Basin	352	21	6.0
4. Fort Worth	181	11	6.1
5. San Joaquin Valley	169	10	5.9
6. Delta	308	16	5.2
7. New York Petroleum	212	7	3.3
Group D			
1. Gulf Coast	929	151	16.3
2. Southwest Texas	461	45	9.8
3. Dallas	433	30	7.0
4. Mid-Continent	553	35	6.3
5. Southern California Petroleum	597	25	4.2
Total applications from Sections			528
Miscellaneous			28
Foreign			25
Total applications received, Jan. 1-Aug. 31			581

Proposed for Membership, Petroleum Branch, AIME

TOTAL AIME membership on July 31, 1955, was 23,073; in addition 1,918 Student Associates were enrolled.

PETROLEUM BRANCH ADMISSIONS COMMITTEE

Virgil B. Harris, chairman; C. C. Harter; Charles Hudson; Raoul J. Bethancourt; Oscar K. McElheney; Jack Wahl.

INSTITUTE ADMISSIONS COMMITTEE

P. D. Wilson, chairman; F. A. Ayer, A. C. Brinker; R. H. Dickson; T. D. Jones; F. T. Hanson; Sidney Rolle; O. B. J. Fraser; F. T. Sisco; Frank T. Weems; R. L. Ziegfeld; R. B. Caples; F. W. McQuiston, Jr.; Arthur R. Lytle; H. R. Wheeler; L. P. Warrimer; J. H. Scaff.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

California
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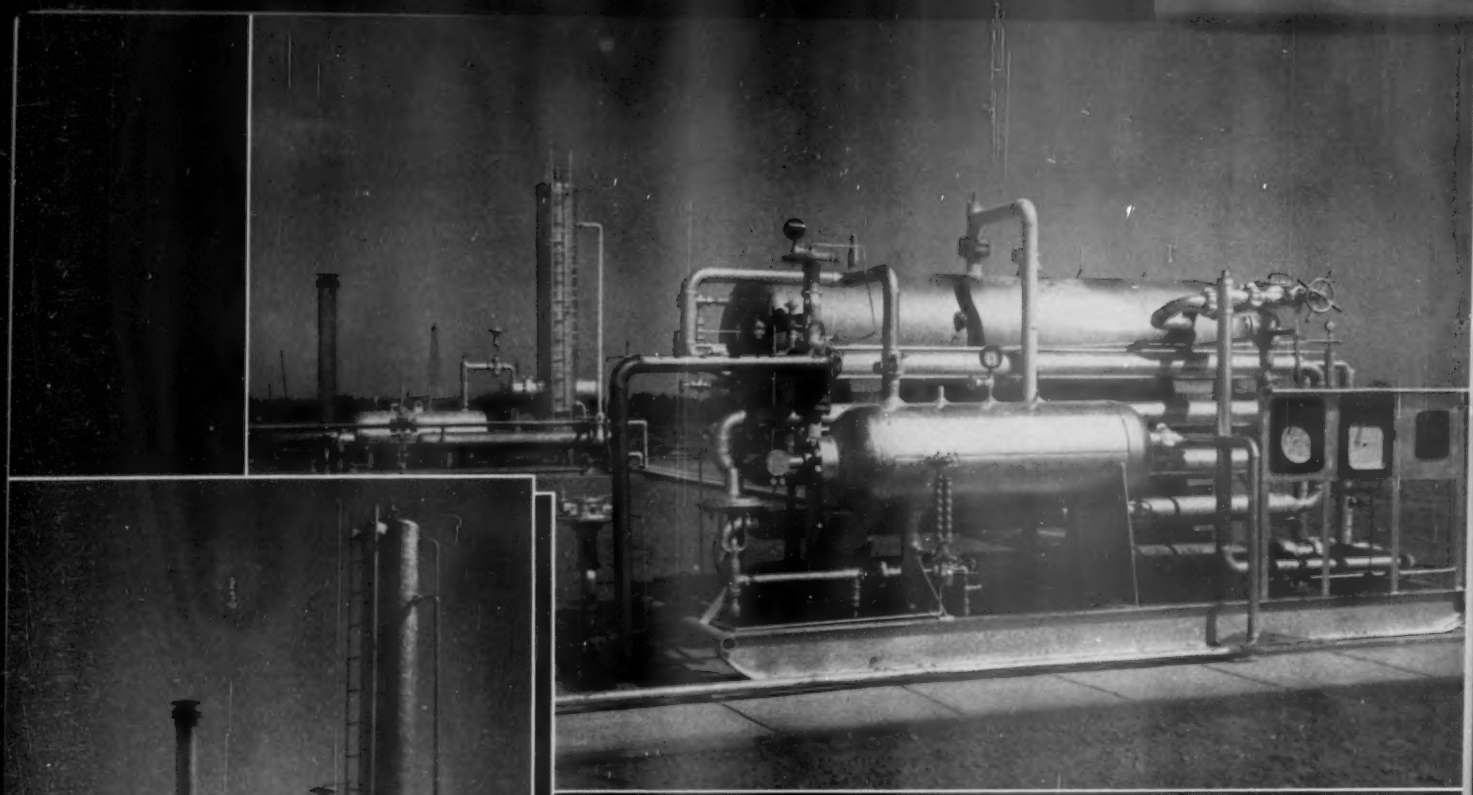

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7-11-53

TECHNICAL NOTE 303

NEW APPARATUS for STUDYING PRESSURE INDUCED FRACTURING in REFERENCE to LOST CIRCULATION

A. J. TEPLITZ
E. M. POHORILES
JUNIOR MEMBER AIME
J. K. RODGERS

GULF RESEARCH & DEVELOPMENT CO.
PITTSBURGH, PA.

INTRODUCTION

This note is presented in order to call attention to a newly developed laboratory apparatus that appears to have interesting possibilities for the study of lost circulation of the pressure-parting type, for a more realistic evaluation of sealing materials for this type of loss, and for investigation of other aspects of hydraulic fracturing.

A study of lost circulation, conducted jointly by operating divisions of the Gulf Oil Corp. and the Gulf Research & Development Co., has been in progress for the past few years. Earlier phases of the study dealt with mechanical factors contributing to loss of returns in laminar type sediments.[1]

One aspect of this type of loss which has been widely discussed in the literature and elsewhere concerns the geometry of the fractures into which such losses occur. This subject is not merely a philosophical one, but has an important bearing on procedures for combating lost circulation difficulties and on other well operations.

The further course of the collaborative studies previously mentioned has produced some information on this subject which, though limited in amount, is believed to be significant. In several typical cases of lost circulation in laminated shale and sand formations, the wells have been surveyed with instruments[2,3] capable of detecting the points of loss with considerable accuracy. These wells were located in the Gulf Coast of Texas and Louisiana, in the Texas Panhandle, and in the Rocky Mountain area. In each of these instances the loss was shown to be occurring at some distance removed from the bottom of the hole and sharply confined to a very narrow interval, less than 1 ft in thickness.

It is rather difficult to imagine that fractures of a vertical nature[4] would be of the limited extent indicated by the surveys in these wells. Furthermore, the high rates of loss at relatively low pressure differentials observed in some of these instances together with the narrow intervals involved would appear to require the radial flow pattern which would be associated with a more or less horizontal fracture plane.

In view of the foregoing observations and records of successful squeeze cementing operations, in attempting to construct a laboratory apparatus for simulating pressure induced lost circulation, it was decided that the design should be based on a horizontal type of fracture.

It was realized that[5,6] the production of horizontal fractures in a formation with non-penetrating fluid requires some mechanism for transmitting vertical components of the hydraulic forces to the plane of parting. This was accomplished, as will be evident in the description of the apparatus that follows, by providing recesses in the wall of the borehole which are believed to be representative of wellbore configuration found in Gulf Coast wells. The possible influence of such borehole irregularities on both pressure fracturing and the treatment of lost circulation appears to have been neglected in many studies of these subjects.

It is believed that the present apparatus, incorporating features that take into account some of the factors mentioned, will provide means of gaining a further understanding of pressure induced fracturing and possibly for more realistically evaluating the numerous sealing agents, particularly the non-time-setting materials employed in treating the pressure-parting type of loss.

DESCRIPTION OF APPARATUS

The test cell used in the laboratory investigations is shown in Fig. 1. A schematic diagram of the entire system is shown in Fig. 2.

Manuscript received in Petroleum Branch office on July 5, 1955.
[1]References given at end of paper.

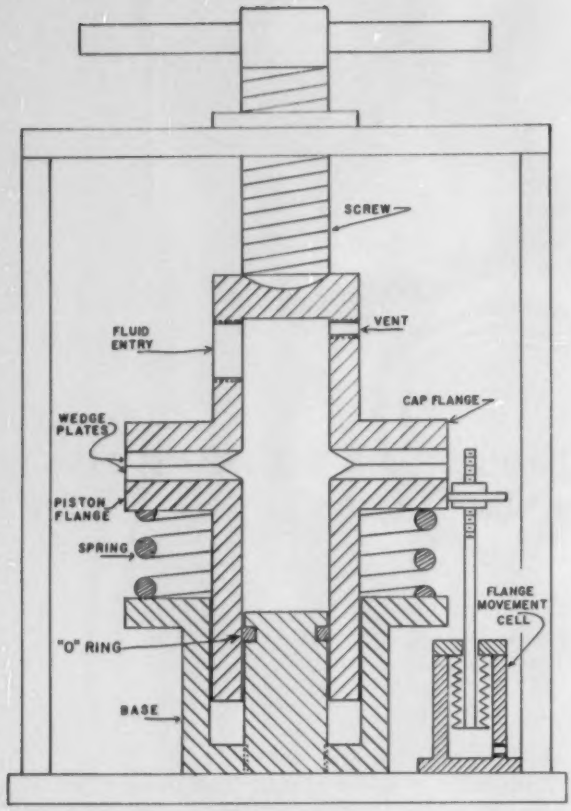

FIG. 1 — LOST CIRCULATION TEST CELL.

The mechanism functions in the following manner:

A. The test cell is subjected to a load applied by the screw jack. The applied load is determined by the deflection of the calibrated spring. The force existing on the flange faces is readily calculated from the applied load.

B. A two-pen recording gage indicates both the fluid pressure in the system and the flange displacement. The flange displacement is measured by means of a bellows which translates linear movement into pressure.

C. The mud reservoirs contain the test fluid to which various concentrations of lost circulation materials have been added.

D. Oil is pumped into the mud reservoir to displace the test fluid.

The test procedure is to displace the test fluid into the cell and bleed off the air in the system. After closing the bleed-off valve, pressure is built up until a parting of the "wedge" plates occurs. The test fluid containing the sealing agents is then continually pumped through the system. Throughout the entire test the internal bore pressure, wedge plate displacement, time, and volume of fluid are recorded.

DISCUSSION

The initial tests were made with the flanges butted together so that the "wellbore" was flush. With a flush bore it was found, as expected, that although filtrate from the test fluid would start to seep through the flange joint at a relatively low pressure, the flow would soon be plugged off by the deposition of a comparatively minor quantity of filter cake at the crevice; thereafter the pressure could be raised to values greatly exceeding those corresponding to the applied load without parting the flange faces.

The test cell was then modified to provide a simulated borehole recess by the introduction of a pair of beveled plates between the flanges, and it was found that parting of the plates could be produced under stress conditions more nearly conforming with field experience. With a non-penetrating fluid, the conditions existing when rupture occurs in this apparatus are given by the expression:

$$P = \frac{L + Df\,Ks}{A}$$

Where: P = break-through pressure, psi
L = applied load, pounds
Df = flange displacement, inches
Ks = spring constant, pounds per inch of deflection
A = projected area of bore recess, square inches

In the operation of this apparatus there are obvious departures from actual well behavior. A fixed load is employed in the apparatus, whereas in well formations uniform loading is approached so that the rupturing pressure is not dependent on the areal extent of the wellbore recess. Furthermore, the combination of the difference in loading and the dissimilarity in elastic properties of the materials involved would result in differences in the mechanism of fracture propagation in the two systems. However, the conditions for the initiation of rupture are essentially the same in the two cases and in some experiments the functioning of the apparatus has been made even more realistic by cementing actual formation cores between the flanges in lieu

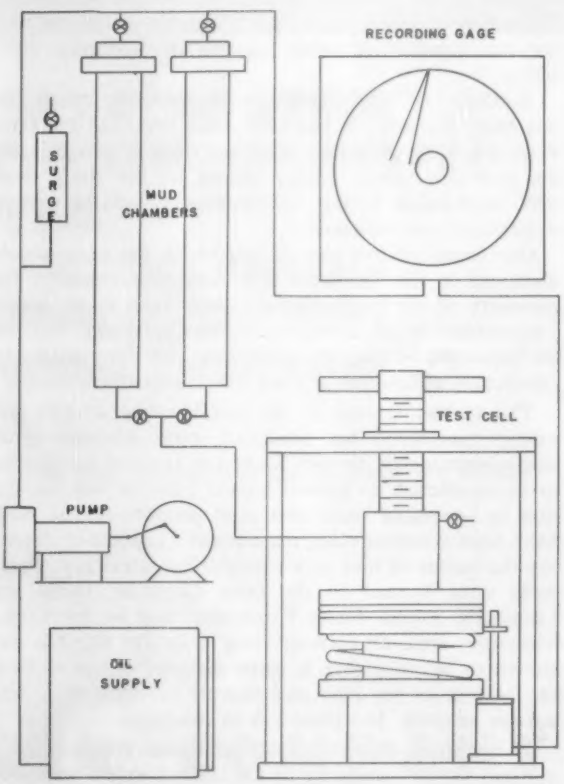

FIG. 2 — SCHEMATIC DIAGRAM OF LOST CIRCULATION APPARATUS.

of the beveled plates. For this purpose the centers of the cores were bored out to conform with the internal dimensions of the apparatus and V-shaped rings were cut in the bore walls of the cores to provide the recesses necessary for horizontal rupture.

Preliminary results of experimentation with this apparatus indicate that of the non-time-setting sealing agents, the hard granular materials are the most effective in stopping losses and that the actual seal occurs in the recess itself rather than within the fracture. These results suggest that the most efficient method for stopping such losses is to deposit within the recess a concentrated mass of material with sufficient hardness and impermeability to prevent the transmission to the formation of the vertical components of the hydraulic forces within the borehole.

The work with this apparatus now in progress is expected to lead to other interesting developments on the mechanism of pressure induced fracturing.

ACKNOWLEDGMENTS

The authors wish to express appreciation to the management of the Gulf Research & Development Co. for permission to publish this paper, and to R. D. Wyckoff and T. Bardeen for their contributions in discussions that led to the development of the apparatus.

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★★★

TECHNICAL NOTE 302

TWO ERRORS in PRESSURE MEASUREMENT USING SUBSURFACE GAUGES

W. J. AINSWORTH
STUDENT ASSOCIATE AIME
MURRAY F. HAWKINS, JR.
MEMBER AIME

LOUISIANA STATE UNIVERSITY
BATON ROUGE, LA.

INTRODUCTION

In all types of subsurface pressure gauges the extension which occurs in the pressure-sensitive element is a function of the difference between the external (well or calibration) pressure and the internal pressure within the gauge, rather than a function of the external pressure only. The internal pressure is near atmospheric and depends upon (a) the quantity of air sealed within the gauge at the time of calibration or measurement, (b) the quantity of moisture (liquid water), if any, sealed within the gauge, and (c) the temperature at which the calibration or well measurement is made. Part of this correction for the change of internal pressure with temperature is taken care of by the customary temperature coefficient of the gauge. However, part of it is not, and while this portion may be only a few psi, it is nevertheless predictable or preventable, and should be considered in precision measurements.

ERROR NO. 1

If air is sealed in the gauge at the same temperature and pressure for both the calibration and the well measurements, the usual temperature correction will take care of any difference between calibration and well measurement temperatures. However, if air is sealed within the gauge at temperature T_1 and pressure P_1 at calibration but at temperature T_2 and pressure P_2 for a well measurement, because different amounts of air are sealed within the gauge in each case, the internal pressure at, or corrected to, calibration temperature T_c will be different by

$$\Delta P = T_c[P_1/T_1 - P_2/T_2]$$

where all temperatures and pressures are absolute. The calibration temperature is used, and not the well measurement temperature, because the usual temperature correction reduces the well measurements to calibration temperature. The correction term as calculated by the above equation is separate from, and in addition to, the usual temperature correction.

Example: $T_1 = 540°R$, sealing temperature at calibration
$P_1 = 14.7$ psia, sealing pressure at calibration
$T_2 = 460°R$, sealing temperature at well
$P_2 = 14.7$ psia, sealing pressure at well
$T_c = 660°R$, calibration temperature
$\Delta P = 660\ [14.7/460 - 14.7/540] = 3.1$ psi

While this error is small even under these somewhat maximal conditions, it nevertheless represents a practical situation which did occur, and which as a matter of fact gave rise to this note. Where ΔP is positive, as above, the correction is added to the measured pressure; where negative, subtracted from the measured pressure. This correction should also be considered in successive calibration runs where the gauge, for example, may be warm from a previous calibration at an elevated temperature.

Manuscript received in Petroleum Branch office on May 4, 1955.

ERROR NO. 2

Where a small quantity of moisture (liquid water) is sealed within the gauge at atmospheric conditions, the increased vapor pressure of the water at higher well or calibration temperatures will cause an increase in internal pressure. This moisture will come presumably from condensation within the gauge following temperature changes, from moisture on the operator's hands, and from atmospheric moisture (rain, mist, fog, etc.). Calculation shows that approximately 0.2 cc of water (three to four drops) is sufficient to saturate the air within an Amerada RPG-3 Gauge at 160°F, at which temperature the vapor pressure of water is about 5 psia. As the vaporization occurs in a sealed volume, the increase in internal pressure will be in excess of this 5 psi. At higher temperatures the pressures will be higher; however more water will be required to saturate the air within the gauge.

Some experimental work was carried out with an Amerada RPG-3 Gauge at 200°F fitted with a 1,000 psi element, both with a dry recording chamber and with a small amount of water added. The results directly proved the existence of the error due to the presence of moisture, and, it is felt, indirectly, due to the differences in sealing temperatures and pressures, as both effects may be ascribed simply to an increase in the moles of gas within the recording chamber.

SUMMARY

In precision measurements the error introduced by sealing the gauge during a well test at a different temperature and pressure from that of calibration may be corrected for by using the equation presented, or it may be prevented by taking care always to seal the gauge at near calibration conditions. The error introduced by sealing moisture in the gauge may be prevented by taking care to keep moisture out of the gauge, or by removing the moisture by either warming or evacuating the gauge. Both of these errors are independent of the range of pressure measurement and the type of gauge, and are in addition to the usual temperature correction.

ACKNOWLEDGMENT

Appreciation is expressed to W. B. Kendall, Geophysical Research Corp., Tulsa, Okla., who pointed out the error from differences in sealing temperatures during some winter work in Canada. ★★★

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The ISOCHRONAL PERFORMANCE METHOD of DETERMINING the FLOW CHARACTERISTICS of GAS WELLS

M. H. CULLENDER | PHILLIPS PETROLEUM CO.
BARTLESVILLE, OKLA.

T. P. 4120

ABSTRACT

The performance characteristics of gas wells producing from formations which fail to stabilize within a relatively short period of time are obscured by the interrelation of the coefficient (C) and the slope "n" of the conventional back-pressure curve

$$Q = C(P_t^2 - P_a^2)^n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

An empirical method is presented whereby the characteristic or true slope (n) of the back-pressure curve may be determined for a particular gas well.

For those gas wells which do not stabilize within a relatively short period of time, the coefficient (C) is considered as a variable with respect to time and as a constant only with respect to a specific time. Thus, the back-pressure performance of such a well is presented as a series of parallel curves, each curve representing the performance of the well at the end of a given time interval.

Through use of the method presented, a simple pressure gradient is developed and maintained within the drainage area around a producing gas well during the test period in order that the variation of the coefficient (C) with respect to time does not obscure the true value of the slope.

INTRODUCTION

The back-pressure method of testing gas wells as set forth by Schellhardt and Rawlins[1] is dependent upon the requirement that a series of flow rates and corresponding pressure data be obtained under stabilized conditions. These data are then plotted on logarithmic coordinates of flow rate (Q) vs difference in squared pressures ($P_t^2 - P_a^2$) in order to determine the constants (C) and (n) for Equation 1. With respect to this method of presenting the performance characteristics of a gas well, it should be pointed out that although Equation 1 is an empirical relationship, the form of the equation was justified to a considerable extent by an independent development by Muskat and Botset.[2] This development was theoretical in nature; however, certain assumptions with respect to the type of flow existing (viscous vs non-viscous) were made which may or may not be correct.

As the use of the method presented by Schellhardt and Rawlins spread through the industry, it became evident that the method of testing was applicable for those wells which approached stabilized producing conditions within a relatively short period of time. Performance characteristics could not be determined by this method, however, for wells which approached stabilized producing conditions slowly over a considerable period of time. This characteristic of "slow stabilization" has generally been associated with gas wells producing from reservoirs of low permeability.

As the demand for natural gas continued to grow through the years, a great number of wells were completed in reservoirs of low permeability which exhibited "slow stabilization" characteristics. Consequently, the problem of determining the true performance characteristics of these wells became more apparent. It is with this problem in mind that the isochronal performance method of determining the flow characteristics of gas wells is presented.

Paper presented at Petroleum Branch Fall Meeting in Dallas, Oct. 18-21, 1953. Original manuscript received in Petroleum Branch office on July 20, 1953. Revised manuscript received on May 26, 1955.

[1]References given at end of paper.

Discussion of this and all following technical papers is invited. Discussion in writing (3 copies) may be sent to the offices of the Journal of Petroleum Technology. Any discussion offered after Dec. 31, 1955, should be in the form of a new paper.

METHOD

The term "isochronal" has been adopted as being descriptive of the method, because only those conditions existing as a result of a single disturbance of constant duration are considered as being related to each other by Equation 1. The expression, "single disturbance of constant duration" is intended to define those conditions existing around a well as a result of a constant flow rate existing for a specific period of time from shut-in conditions. Under actual test conditions this requirement is rarely satisfied; however, a very similar condition may be established by starting a well on production and allowing the well to produce without further outside or mechanical adjustments. In this manner a simple pressure gradient is established around the wellbore, as opposed to a complex pressure gradient resulting from two or more mechanical changes in the flow rate from shut-in conditions. The procedure employed to obtain the necessary performance data is to open a well from shut-in conditions and obtain rate of flow and pressure data at specific time intervals during the flow period without disturbing the rate of flow. After sufficient data have been obtained, the well is shut-in and allowed to return to a shut-in condition comparable to that existing at the time the well was first opened. The well is again opened at a different rate of flow with data being obtained at the same time intervals as before. The procedure may be repeated as many times as necessary to obtain the desired number of data points.

Certain assumptions are made in order to justify the presentation of the performance characteristics of a gas well as a series of parallel curves with a constant slope (n) and a constant coefficient (C) only with respect to specific time intervals. These assumptions are as follows:

1. The characteristic slope (n) of the performance curves of a gas well is independent of the drainage area. It is established almost immediately after the well is opened.

2. Under simple gradient conditions, the variation of the performance coefficient (C) with respect to time is independent of the rate of flow and pressure level.

MacRoberts[3] has derived an equation relating the recession of the radius of drainage of a producing gas well to the time of production for the case of radial Darcy-type flow (equivalent to the case of a gas well with a characteristic performance slope of 1.00). The final equation was necessarily based on certain assumptions with respect to conditions within the drainage area which may or may not be correct.

This equation is as follows:

$$t = \frac{(\text{Const.})\, r_1^2}{(P_1^2 - P_2^2)} \left[1 - \frac{1}{2 \log \frac{r_1}{r_2}} \right] \quad . \quad . \quad . \quad . \quad (2)$$

If the recession of the radius of drainage with respect to time is visualized as being equivalent to the decline in the coefficient (C) of the back-pressure performance of a gas well with time, examination of Equation 2 would indicate that pressure level has some affect on the variation of the performance coefficient (C). If this is true, the affect is of such low magnitude that it is not determinable within the range of field data obtained to date.

TABLE 1 — PERFORMANCE DATA OF GAS WELL NO. 1

Date	SIP, psia	Duration of Flow, Hours	Mcf/D @ 14.65 psia	$P_f^2 - P_s^2$
10-3-44	435.2	24	9,900	97.70
10-24-44	436.8	1	4,656	22.52
		3	4,587	27.26
		23	4,440	38.67
12-11-45	394.7	0.1	2,016	4.61
		0.2	2,009	5.68
		0.5	2,001	7.10
		1	1,994	8.26
		3	1,980	10.38
		24	1,947	14.56
1-11-46	390.7	0.1	2,991	7.64
		0.2	2,977	9.21
		0.5	2,956	11.56
		1	2,941	13.28
1-15-46	394.0	0.2	7,327	26.09
		0.5	7,199	31.25
		1	7,092	35.52
		3	6,887	42.99
1-17-46	391.1	0.5	2,952	11.23
		1	2,937	12.87
		3	2,905	15.72
12-5-46	381.0	0.1	4,158	10.61
		0.2	4,130	12.72
		0.5	4,086	15.91
		1	4,052	18.40
		3	3,989	22.17

FIELD DATA

The data obtained on a typical gas well (Well No. 1) producing from a formation exhibiting slow stabilization characteristics with respect to time are shown in Fig. 1. The data were obtained at various times during the period 1944 to 1946. These data are presented in Table 1. Points of interest are the fact that the characteristic slope of 0.867 is established within a very few minutes after the well is opened and the fact that the decline in the coefficient (C) is a variable with respect to time.

In the case of the three data points shown on the 24-hour curve, these were the first points of three different back-pressure tests taken in the manner described in Monograph 7. The data obtained at the end of the succeeding flow rates in each case are shown in Fig. 2 and Table 2. Curve A represents the data obtained during a reverse sequence test, while Curves B and C represent data obtained during normal sequence tests in which the initial rates of flow were considerably

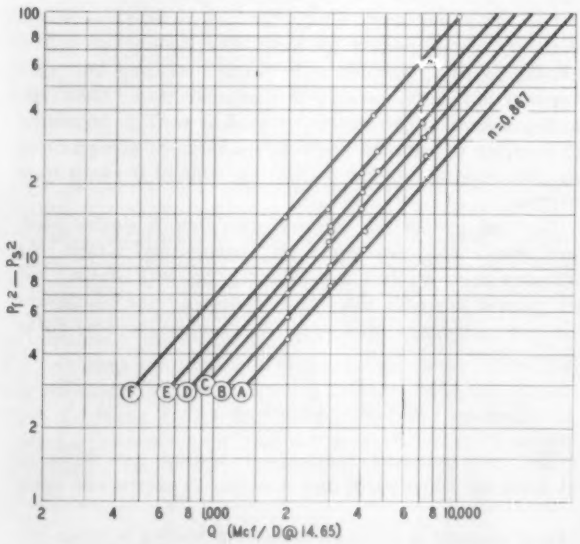

FIG. 1 — ISOCHRONAL PERFORMANCE CURVES OF GAS WELL NO. 1 (SLOPE = 0.867)

Curve A: 0.1-hour duration of flow
Curve B: 0.2-hour duration of flow
Curve C: 0.5-hour duration of flow
Curve D: 1.0-hour duration of flow
Curve E: 3.0-hour duration of flow
Curve F: 24.0-hour duration of flow

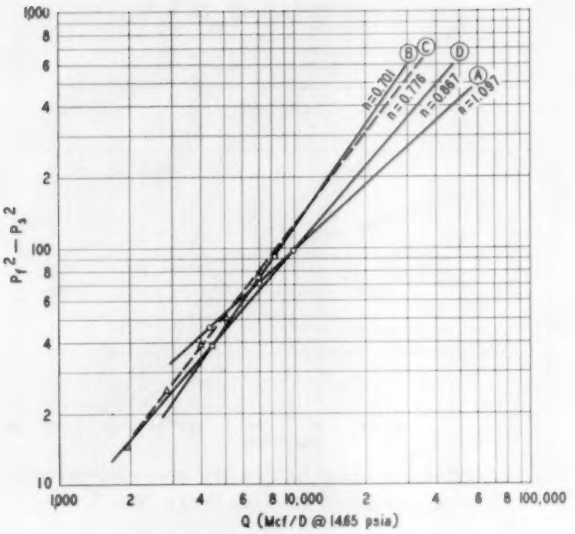

FIG. 2 — BACK-PRESSURE TEST DATA OF GAS WELL NO. 1.

Curve A: 24-hour, reverse sequence back-pressure test (slope = 1.097).
Curve B: 24-hour, normal sequence back-pressure test (slope = 0.701).
Curve C: 24-hour, normal sequence back-pressure test (slope = 0.776).
Curve D: 24-hour, isochronal performance curve (slope = 0.867).

TABLE 2 — BACK-PRESSURE TEST DATA OF GAS WELL NO. 1

Date	SIP, psia	Duration of Flow, Hours	Mcf/D @ 14.65 psia	$P^2_f - P^2_s$
10-3-44	435.2	24	9,900	97.70
		24	7,091	70.73
		24	4,360	46.16
10-24-44	423.6	23	4,440	38.67
		25	6,982	75.17
		22	8,212	92.35
12-11-45	394.7	24	1,947	14.56
		24	2,841	25.07
		26	3,941	38.82
		22	5,165	50.53

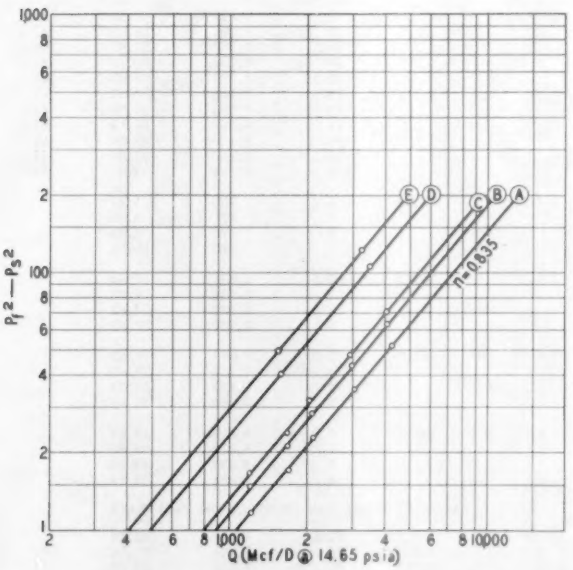

FIG. 3 — ISOCHRONAL PERFORMANCE CURVES OF GAS WELL NO. 2 (n = 0.835) (SLOPE = 0.835)

Curve A: 1-hour duration of flow
Curve B: 2-hour duration of flow
Curve C: 3-hour duration of flow
Curve D: 24-hour duration of flow
Curve E: 72-hour duration of flow

different. Curve D is a reproduction of the 24-hour curve shown in Fig. 1. It should be noted that although the three back-pressure curves represent different performance conditions, those conditions were a result of complex pressure gradients established during the test. The initial points of each back-pressure test represent the formation characteristics, while the other data points represent complex conditions which have no significance. It is the author's opinion that the characteristic slope still applies to the complex points and that the difference in performance exists only in the coefficient (C). If the slope of 0.867 is applied to the complex points, it can be seen that the coefficient obtained in each case can be considered to be the result of an "effective" time, which has no permanent significance and which is not equal to the total elapsed time nor the elapsed time since the last change in flow rate.

If a well of this type is allowed to produce at some rate until the coefficient becomes constant, an increase in the flow rate will cause the coefficient to immediately *increase*. It will then gradually decline to the stabilized value as the new disturbance moves outward to the boundary of the drainage area. A decrease in the flow rate of such a well producing under stabilized conditions will cause the coefficient to immediately *decrease*. Then it will gradually increase to the stabilized value as the pressure builds up in the drainage area to again approach a simple gradient.

It is apparent that extrapolation of data obtained under complex conditions can lead to very serious error with respect to the projected performance.

The data obtained on another well (Well No. 2) are shown in Fig. 3 and Table 3. Again the characteristic slope of 0.835, developed under short-time flow conditions, is applicable to long-time flow conditions. Also, the decline in the coefficient (C) is a variable with respect to time.

The data on another well (Well No. 3) are shown in Fig. 4 and Table 4. During Dec., 1951, the isochronal performance data represented by Curves A through D were obtained at 0.5-hour, 1-hour, 2-hour, and 3-hour time intervals respectively. The shut-in pressure on the well at that time was approximately 352 psia. During 1944, when the shut-in pressure of the well was 441.6 psia, a flow test of nine days duration was taken on this well. The only short-time data point obtained during this test was the 1-hour data point shown just to the right of Curve B at the flow rate of 1,229 Mcf/D. The 23.5-hour, 70.5-hour, and 214-hour performance of the well represented by Curves E, F, and G were obtained by application of the characteristic slope of 0.948 to data points obtained at the respective time periods. Curve H represents the average curve of 0.948 slope through data obtained during annual three-day production tests into the pipeline for the years 1945 through 1953. During this time the three-day shut-in pressure of the well declined from 417.7 psia to 336.1 psia, and the three-day working pressure declined from 369.2 psia to 298.6 psia. It should be realized that production rates during the three-day annual production tests must be gradually increased during the first 24-hour period due

TABLE 3 — PERFORMANCE DATA OF GAS WELL NO. 2

Date	SIP, psia	Duration of Flow, Hours	Mcf/D @ 14.65 psia	$P_t^2 - P_s^2$
2-18-48	436.0	1	1,224	8.85
		2	1,215	11.70
		3	1,200	16.77
3-2-48	435.8	1	4,262	32.22
		2	4,114	63.35
		3	4,022	70.28
		24	3,495	106.70
		72	3,238	122.43
3-23-48	434.6	1	1,710	17.09
		2	1,691	21.11
		3	1,680	23.77
		24	1,599	40.46
		72	1,562	49.57
7-25-49	434.4	1	2,107	22.77
		2	2,073	28.34
		3	2,054	31.88
7-26-49	432.7	1	3,057	35.20
		2	2,986	43.09
		3	2,942	48.07
7-27-49	432.4	1	4,208	51.39
		2	4,061	62.59
		3	3,963	69.23

to metering restrictions. This gradual increasing of the rate of flow results in a more complex pressure gradient around the well than would be caused by a single disturbance of constant or slowly decreasing magnitude. A complex gradient of this type manifests itself in the form of "effective" time—smaller than actual time from shut-in conditions. It might be pointed out that a drastic reduction in flow rate during a test results in a complex gradient that increases the "effective" time with respect to actual time.

Data of this type, wherein the performance of a well is reasonably constant with respect to C and n at comparable time intervals and different pressure levels, serve as the basis for the conclusion that the variation of the coefficient (C) with respect to time is independent of rate of flow and pressure level.

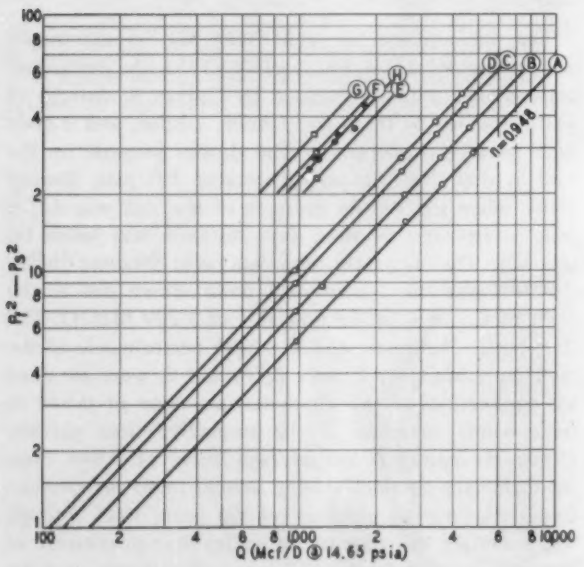

FIG. 4 — ISOCHRONAL PERFORMANCE CURVES OF GAS WELL NO. 3 (SLOPE = 0.948).

Curve A: 0.5-hour duration of flow
Curve B: 1.0-hour duration of flow
Curve C: 2-hour duration of flow
Curve D: 3-hour duration of flow
Curve E: 23.5-hour duration of flow
Curve F: 70.5-hour duration of flow
Curve G: 9-day duration of flow
Curve H: average 3-day performance

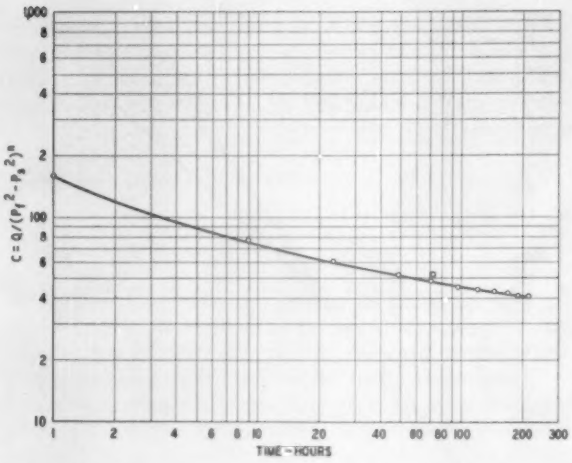

FIG. 4a — RELATIONSHIP OF COEFFICIENT OF PERFORMANCE AND TIME OF GAS WELL NO. 3.

It is sometimes difficult to visualize the variation of the coefficient (C) with respect to time by the examination of data presented in the manner of Fig. 4. It is often advisable to present the data in the form shown in Fig. 4a. Herein the variation of C with respect to time during the nine-day flow period is more readily apparent than in Fig. 4. The point representing Curve H of Fig. 4 is shown just above the curve in Fig. 4a at the time of 72 hours.

A number of wells at low flow rates perform with a slope of 1.00 and exhibit a breaking-point above which flow rate the well performs with a characteristic slope less than 1.00. The data obtained on such a well (Well No. 4) are shown in Fig. 5 and Table 5. The flow

TABLE 4 — PERFORMANCE DATA OF GAS WELL NO. 3

Date	SIP, psia	Duration of Flow, Hours	Mcf/D @ 14.65 psia	$P_t^2 - P_s^2$	Coefficient
10-11-44	441.6	1	1,229	8.62	159.5
		9	1,202	18.01	77.6
		23.5	1,187	23.07	60.6
		49	1,176	26.71	52.2
		70.5	1,171	28.81	48.4
		96.5	1,166	30.52	45.6
		120	1,163	31.56	44.1
		144	1,161	32.13	43.3
		169	1,159	32.89	42.3
		190	1,157	33.54	41.4
		214	1,156	33.91	40.9
12-3-51	352.4	0.5	983	5.37	
		1	977	6.96	
		2	970	8.93	
		3	965	10.19	
12-4-51	352.3	0.5	2,631	15.54	
		1	2,588	19.82	
		2	2,533	24.63	
		3	2,500	27.72	
12-5-51	351.0	0.5	3,654	21.63	
		1	3,565	27.40	
		2	3,453	34.03	
		3	3,390	37.97	
12-6-51	349.5	0.5	4,782	28.84	
		1	4,625	35.96	
		2	4,438	43.98	
		3	4,318	48.96	
	ANNUAL THREE-DAY PRODUCTION TEST DATA				
4-5-45	417.7	72.5	1,818	43.94	
7-13-45	403.2	72	1,848	41.16	
5-10-46	389.7	72	1,665	35.57	
5-28-47	389.9	72.25	1,457	34.65	
5-17-48	378.5	71.83	1,269	28.81	
6-17-49	371.7	72	1,389	31.96	
5-23-50	365.5	71.75	1,438	34.16	
5-29-51	355.0	72.25	1,195	27.23	
5-26-52	348.5	71.5	1,073	24.97	
7-7-53	336.1	72	1,164	27.43	

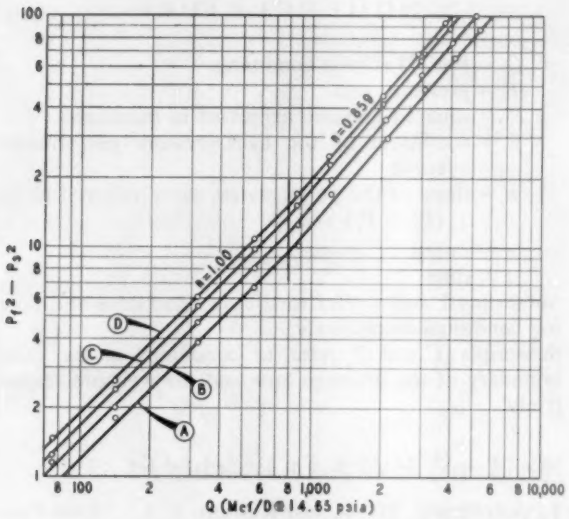

FIG. 5 — ISOCHRONAL PERFORMANCE CURVES OF GAS WELL NO. 4: BELOW 800 MCF/D (SLOPE = 1.000) ABOVE 800 MCF/D (SLOPE = 0.859).

Curve A: 0.5-hour duration of flow
Curve B: 1.0-hour duration of flow
Curve C: 2.0-hour duration of flow
Curve D: 3.0-hour duration of flow

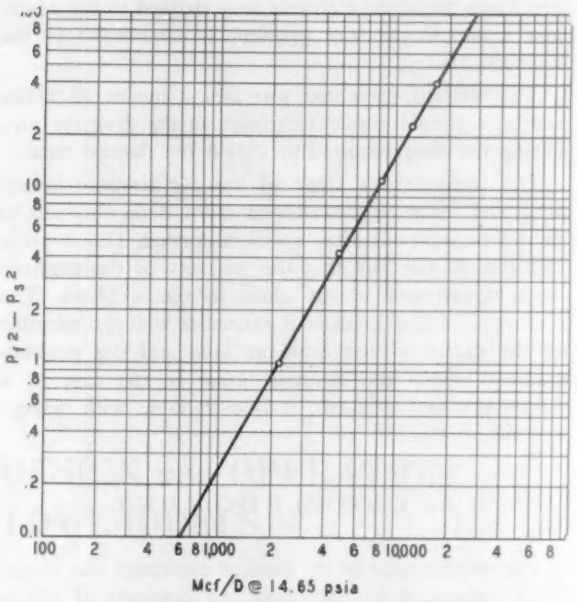

FIG. 6 — STABILIZED PERFORMANCE CURVE OF GAS WELL NO. 5 (SLOPE = 0.554).

rates range from 76 Mcf/D to 5,373 Mcf/D. The point of interest is the breaking-point with respect to the slope (n) that occurs at approximately 800 Mcf/D. A satisfactory explanation for the existance of such a point of interest is the breaking-point with respect to of comparable capacity producing from the same formation as the above well which perform over the full range of flow conditions with characteristic slopes less than 1.00. These characteristic slopes, as determined by isochronal performance data, have been found to exist between the limits of approximately 0.5 to 1.0.

Certain gas wells stabilize so rapidly that there is no necessity for obtaining isochronal performance data. The data on such a well (Well No. 5) are presented in Fig. 6 and Table 6. Each flow was of 1-hour duration. However, the three high flow rates were obtained without closing the well between flows, while the three low flow rates were each obtained from shut-in conditions. (The smallest flow rate of 570 Mcf/D is not shown on Fig. 6 since $[P_f^2 - P_s^2]$ was equal to 0.09. The point lies on the performance curve, however.) Although the duration of flow in each case was 1 hour, the working pressure for each flow remained constant almost from the beginning of the flow period.

TABLE 5 — PERFORMANCE DATA OF GAS WELL NO. 4

Date	SIP, psia	Duration of Flow, Hours	Mcf/D @ 14.65 psia	$P^2_f - P^2_s$
9-28-49	449.9	0.5	76	0.95
		1	76	1.16
		2	76	1.26
		3	76	1.47
9-30-49	450.1	0.5	143	1.79
		1	143	2.00
		2	143	2.42
		3	143	2.61
10-3-49	450.2	0.5	576	6.62
		1	575	8.06
		2	573	9.72
		3	572	10.94
10-4-49	449.6	0.5	1,237	16.96
		1	1,229	19.28
		2	1,219	22.49
		3	1,212	24.48
10-5-49	449.3	0.5	2,148	29.33
		1	2,116	35.37
		2	2,083	41.04
		3	2,065	44.56
10-6-49	448.5	0.5	3,079	48.22
		1	3,017	55.08
		2	2,947	63.52
		3	2,902	68.25
10-7-49	447.4	0.5	4,218	65.70
		1	4,087	76.22
		2	3,936	86.85
		3	3,852	92.87
10-11-49	448.6	0.5	5,373	86.49
		1	5,136	99.42
		2	4,887	111.71
		3	4,756	118.45
10-14-49	448.7	0.5	326	3.83
		1	325	4.67
		2	324	5.50
		3	323	6.12
11-2-49	449.3	0.5	888	10.03
		1	881	12.49
		2	874	15.14
		3	870	16.86

TABLE 6 — PERFORMANCE DATA OF GAS WELL NO. 5

Date	SIP, psia	Duration of Flow, Hours	Mcf/D @ 14.65 psia	$P^2_f - P^2_s$
3-30-50	439.0	1	8,373	11.27
		1	12,484	23.25
		1	16,817	40.60
4-3-50	439.9	1	570	0.09
4-4-50	439.6	1	2,231	1.01
4-5-50	439.8	1	4,841	4.32

CONCLUSIONS

The conclusions to follow are based on the premise that the liquid saturation around the wellbore does not change materially as a result of the various flow rates.

The performance characteristics of a gas well can be determined from flow data obtained under transient

conditions when the transient is controlled to the extent that a simple pressure gradient is established in the drainage area.

The method presented provides a means of maintaining a simple gradient throughout the drainage area during the time required to obtain the desired data.

The characteristic slope of the performance curves of a well may be determined from data obtained at short-time intervals after a well is opened. This is probably due to the fact that the majority of the pressure drop experienced occurs close to the wellbore. The performance coefficient of a particular well is controlled by the extent of the drainage area and the pressure gradient within the drainage area. In the case of a simple pressure gradient, it is a variable with respect to time.

ACKNOWLEDGMENT

The development of the method presented was necessarily influenced by the ideas and concepts of others with whom the writer has been privileged to study well performance. To all such persons, grateful acknowledgment is made.

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NOMENCLATURE

Q = Mcf/D at base conditions
P = pressure, psia
P^2 = squared pressure expressed in thousands
C = coefficient of the back-pressure performance curve
n = slope of the performance curve referred to the $(P_f^2 - P_s^2)$ axis
r = radius
t = time

Subscripts f and s refer to shut-in conditions and flowing conditions respectively.
Subscripts 1 and 2 refer to conditions at the outer boundary of the drainage area and the wellbore respectively.

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SCALING LAWS for USE in DESIGN and OPERATION of WATER-OIL FLOW MODELS

L. A. RAPOPORT
MEMBER AIME

THE CARTER OIL CO.
TULSA, OKLA.

T. P. 4121

ABSTRACT

This paper is intended as an aid in the performance and interpretation of experimental studies of multi-phase flow in porous media. The mathematical formulation of incompressible, two-phase flow phenomena in a three-dimensional porous medium is presented. The resulting equations which account for the effects of gravitational and capillary forces are used to derive general scaling laws permitting accurate representation of water-oil displacement processes by means of experimental flow models. The significance of the scaling laws is examined in the light of the physical concepts of micro-behavior of fluids in porous media. Formulations of scaling conditions obtained by application of dimensional analysis are reviewed. The principles of application and the limitations of flow model studies are discussed.

INTRODUCTION

Most of the problems facing a reservoir engineer involve three-dimensional, two-phase flow systems, influenced by the effects of gravitational and capillary forces. Present computational procedures generally do not permit the evaluation of such systems without introducing greatly simplifying assumptions. The actual reservoir configuration is usually replaced by one or a combination of several "equivalent" linear systems, and the effects of capillarity and gravity are considered to be negligible. While these assumptions may in many instances be justified, there are a number of important practical problems for which the results obtained on the basis of such simplifications remain open to question.

An alternate approach to the problems that are not amenable to analytical treatment consists of seeking their solution by experimental laboratory investigations. The main difficulty of such investigations lies in the fact that multiphase flow phenomena subjected to gravity and capillary forces proceed differently at different rates and in systems of different dimensions. Therefore, unless great discrimination is exercised in selecting the conditions and interpreting the results of laboratory tests, such tests may be entirely misleading in regard to field applications.

The purpose of this paper is to present a theoretical background for the performance of laboratory tests that are more nearly representative of field behavior. It will be shown that simulation of field behavior can be achieved by conducting laboratory tests under conditions selected in accordance with definite scaling laws.

The formulation of conditions required for the scaling of two-phase flow experiments in porous media has been presented in the literature on several occasions.[1,2,3,4] One of these formulations advanced by Leverett[1], cannot be considered applicable to most practical cases inasmuch as it does not cover generally the regime of laminar flow. An adequate treatment, based on the consideration of dimensional analysis, was presented by Engelberts and Klinkenberg.[2] Their treatment, however, is concerned primarily with the scaling of linear flow systems, and hence somewhat limited in scope. Accordingly, the formulation of more general scaling laws, applicable to three-dimensional systems, appeared to be warranted. It appeared, furthermore, desirable to establish this formulation on the basis of a mathematical treatment, rather than by application of general principles of dimensional analysis, to permit more explicit

Paper presented at Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954. Original manuscript received in Petroleum Branch office on Oct. 17, 1954. Revised manuscript received on Aug. 15, 1955.

[1]References given at end of paper.

evaluation of the scaling laws in the light of the multiphase flow concepts currently employed in reservoir engineering. Thus, in the derivation of the scaling laws, particular consideration is given to the roles of the relative permeability and capillary pressure functions, and the possibilities of scaling pore size distributions are examined.

The scaling laws developed in this analysis pertain to incompressible, immiscible, two-phase flow systems and are, therefore, primarily applicable to experimental studies of water-oil displacement. Their application may be extended to investigations of gas-drive, gravity-drainage processes in which the pressure level is sufficiently high to render gas compressibility and solubility effects negligible.

ESTABLISHMENT OF SCALING LAWS

Analytical Procedure

DERIVATIONS

In a three-dimensional, homogeneous, porous medium the simultaneous flow of two immiscible, incompressible fluids such as oil and water may be described by the relations:

$$V_o = -k\frac{k_{ro}}{\mu_o}\nabla(p_o + g\,\rho_o z)^* \quad . \quad . \quad . \quad . \quad (1)$$

$$V_w = -k\frac{k_{rw}}{\mu_w}\nabla(p_w + g\,\rho_w z) \quad . \quad . \quad . \quad . \quad (2)$$

$$V_o + V_w = V \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\nabla V = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The pressures existing in the oil and water phases are related to each other by means of the capillary pressure function, $P_c(S)$, so that:

$$p_w = p_o + P_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

or

$$\nabla p_w = \nabla p_o + \nabla P_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)'$$

The changes in saturation occurring in any one volume element during the displacement of oil by water are described by the continuity equation:

$$f\frac{\partial S}{\partial T} + \nabla V_w = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Elimination of the water and oil flow components V_w and V_o, of the flowing pressure gradients ∇p_w and ∇p_o, and of the flux gradients ∇V_w and ∇V from Equations 1 through 6 results in:

$$f\frac{\partial S}{\partial T} + \frac{d\phi}{dS}\left[u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} + w\frac{\partial S}{\partial z}\right] - \frac{k}{\mu_o}\left[\frac{\partial}{\partial x}\left(\Psi\frac{dP_c}{dS}\frac{\partial S}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Psi\frac{dP_c}{dS}\frac{\partial S}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Psi\frac{dP_c}{dS}\frac{\partial S}{\partial z}\right)\right] - \frac{k}{\mu_o}\,g\triangle\rho\,\frac{d\Psi}{dS}\frac{\partial S}{\partial z} = 0 \quad . \quad . \quad . \quad (7)$$

Equation 7 which accounts explicitly for the frictional, gravitational, and capillary forces may be qualified as the "complete" displacement equation. This equation can be applied to describe the flooding and gravitational segregation behavior of a certain field, or "prototype reservoir," subjected to a given injection (or water influx) and production regime.

One may now consider a scale model consisting of a porous medium and fluid system such that the relative permeability functions and the viscosity ratio of the prototype are duplicated. Under such conditions, implying duplication of the functions ϕ and Ψ, the displacement equation applying to the model may be written as:

$$f'\frac{\partial S}{\partial T'} + \frac{d\phi}{dS}\left[u'\frac{\partial S}{\partial x'} + v'\frac{\partial S}{\partial y'} + w'\frac{\partial S}{\partial z'}\right] - \frac{k'}{\mu'_o}\left[\frac{\partial}{\partial x'}\left(\Psi\frac{dP'_c}{dS}\frac{\partial S}{\partial x'}\right) + \frac{\partial}{\partial y'}\left(\Psi\frac{dP'_c}{dS}\frac{\partial S}{\partial y'}\right) + \frac{\partial}{\partial z'}\left(\Psi\frac{dP'_c}{dS}\frac{\partial S}{\partial z'}\right)\right] - \frac{k'}{\mu'_o}\,g\triangle\rho'\,\frac{d\Psi}{dS}\frac{\partial S}{\partial z'} = 0 \quad . \quad . \quad . \quad (8)$$

Aside from ϕ and Ψ the values of pertinent model parameters such as dimensions, flow rates, porosity, specific permeability, capillary pressure, absolute values of fluid viscosities, and fluid densities are different from those encountered in the prototype and can be, off hand, selected arbitrarily.

This selection can be conveniently effected on the basis of scale ratios between prototype and model parameters, defined by the following equations:

$$L/L' = x/x' = y/y' = z/z' = A \quad . \quad . \quad (9)$$

specifying geometrical similarity between model and prototype;

$$q/q' = B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

specifying that the model is operated at injection (or producing) rates that remain at any time in a constant proportion to those encountered in the prototype;

$$f/f' = C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$k/k' = D \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$\triangle\rho/\triangle\rho' = E \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$\mu_o/\mu'_o = \mu_w/\mu'_w = F \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

specifying the scale ratios of porosity, permeability, fluid density difference and fluid viscosities; and:

$$\frac{dP_c}{dS} \Big/ \frac{dP'_c}{dS} = G, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

which can be considered as resulting from either

$$P'_c = P_c/G \quad . \quad . \quad (15a), \text{ or } P'_c = P_c/G + \Gamma \quad . \quad (15b)$$

From a purely mathematical viewpoint it is sufficient to consider Equation 15 which prescribes proportionality between the derivatives of model and prototype capillary pressure functions. However in subsequent, more detailed physical considerations it will be necessary to examine separately the case corresponding to Equation 15a, specifying direct proportionality between model and prototype capillary pressures, and that corresponding to Equation 15b which implies merely a general linear correlation between model and prototype capillary pressure functions.

Having selected the scale ratios of dimensions, rates of injection and porosities (Equations 9 through 11), the scale ratios of unit flux (flow per unit cross sectional area) and of "homologous" or equivalent operational times are necessarily defined as:

$$V/V' = u/u' = v/v' = w/w' = \frac{q/L^2}{q'/L'^2} = B/A^2. \quad (16)$$

and

$$T/T' = \frac{L}{V/f} \Big/ \frac{L'}{V'/f'} = \frac{A^2C}{B} \quad . \quad . \quad . \quad . \quad (17)$$

or

$$\frac{dS}{dT'} = \frac{A^2C}{B}\frac{dS}{dT} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)'$$

Upon substitution of Equations 9 through 17′ into 8, the equation describing the flow behavior in the model may be expressed as:

*Nomenclature at the end of paper. The z-axis is directed vertically upward (upward flow is positive).

$$f\frac{\partial S}{\partial T}+\frac{d\phi}{dS}\cdot\left[u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}\right]-$$
$$\left(\frac{BF}{ADG}\right)\cdot\frac{k}{\mu_o}\cdot\left[\frac{\partial}{\partial x}\left(\Psi\cdot\frac{dP_c}{dS}\frac{\partial S}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Psi\cdot\frac{dP_c}{dS}\frac{\partial S}{\partial y}\right)\right.$$
$$\left.+\frac{\partial}{\partial z}\left(\Psi\cdot\frac{dP_c}{dS}\frac{\partial S}{\partial z}\right)\right]-\left(\frac{BF}{A^2DE}\right)\cdot\frac{k}{\mu_o}g\triangle\rho\frac{d\Psi}{dS}\frac{\partial S}{\partial z}=0 \quad (18)$$

Comparison of the above Equation 18 with Equation 7 shows that the displacement equation applying to the model becomes identical with that applying to the prototype if:

$$BF=ADG=A^2DE, \quad . \quad . \quad . \quad . \quad . \quad (19)$$

which is equivalent to:

$$E=G/A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19a)$$

and,

$$B/A^2=DG/FA \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19b)$$

INTERPRETATION

For purposes of interpretation, the scaling Equations 19a and 19b may be written respectively as:

$$\left[\frac{\triangle\rho/dP_c}{dL}\right]_{\text{model}}=\left[\frac{\triangle\rho/dP_c}{dL}\right]_{\text{prototype}} \quad . \quad . \quad . \quad . \quad (20)$$

and

$$\left[\frac{dP_c}{dL}\Big/\frac{V\mu_w}{k}\right]_{\text{model}}=\left[\frac{dP_c}{dL}\Big/\frac{V\mu_w}{k}\right]_{\text{prototype}} \quad . \quad (21)$$

By virtue of Darcy's law the expression, $V\mu_w/k$, represents a measurement of the flowing pressure gradient caused by frictional forces. Thus the scaling equations reduce to a statement of the following physical conditions: (1) The ratio of gravitational gradient to capillary pressure gradient must be the same for model and prototype; and (2) The ratio of capillary pressure gradient to flowing pressure gradient must be the same for model and prototype.

The scale ratios determining the design and operational procedure of a model must necessarily be chosen within the limits prescribed by the scaling Equations 19. In turn the selection of the parameters entering into the scaling equations is sufficient for the derivation of all remaining operational scale ratios, particularly those relating the behavior of the model to that of the field in terms of pressure and cumulative injection.

For the flowing pressure drops in the oil phase, defined as:

$$d\bar{p}_o=\nabla(p_o+g\rho_o z)\cdot dL \quad . \quad . \quad . \quad . \quad (22)$$

$$d\bar{p}'_o+\nabla(p'_o+g\rho'_o z')\cdot dL' \quad . \quad . \quad . \quad . \quad (22)'$$

with similar expressions applying to the water phase, the scale ratio is obtained by combination of the above equations with Darcy's law (Equations 1 and 2) and with the scale ratios of dimensions, permeabilities, viscosities and unit flux (Equations 9, 12, 14, and 16). As a result:

$$\frac{d\bar{p}_o}{d\bar{p}'_o}=\frac{V_o}{V'_o}\frac{\mu_o}{\mu'_o}\frac{k'}{k}\frac{dL}{dL'}=\frac{B}{A^2}\cdot F\cdot\frac{1}{D}\cdot A=\frac{d\bar{p}_w}{dp'_w} \quad (23)$$

or by virtue of Equation 19b:

$$d\bar{p}_o/d\bar{p}'_o=d\bar{p}_w/d\bar{p}_w=G \quad . \quad . \quad . \quad . \quad (24)$$

This then indicates that under proper conditions of scaling the flowing pressure drop between any two points in the model remains in a constant proportion to that existing between the homologous points in the field.

The cumulative injection, Q, for the prototype, expressed in terms of pore volumes and corresponding to a certain time, T, counted from the beginning of the displacement process under consideration, is:

$$Q=\frac{1}{\alpha fL^3}\int_o^T qdT \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

Similarly, for the model:

$$Q'=\frac{1}{\alpha f'L'^3}\int_o^{T'} q'dT' \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

By virtue of Equations 10 and 17:

$$q'=q/B, \text{ and } T'=TB/A^2C$$

if model and field are considered at homologous times. Substitution of these two expressions into Equation 26 yields:

$$Q'=\frac{(1/B)(B/A^2C)}{\alpha(f/C)(L^3/A^3)}\int_o^T qdT=Q \quad . \quad . \quad (27)$$

Thus, it is demonstrated that under proper conditions of scaling, homologous times correspond to equal cumulative injections, expressed in terms of model and field pore volumes.

PHYSICAL CONSIDERATIONS

In the preceding mathematical analysis it was implied on one hand that the relative permeability functions applying to model and prototype be the same, and on the other, that the porosity, the specific permeability and the capillary pressure function of the model be treated as independent parameters. From a physical standpoint, however, it is apparent that the above characteristics are inter-dependent and cannot be arbitrarily selected. Thus, while the conditions expressed by Equations 19 are sufficient to achieve proper scaling from a mathematical or macroscopic viewpoint, additional considerations regarding the micro-behavior of fluids in porous media are required to complete the definition of the scaling laws. The key to these additional, physical considerations lies in the manner in which model and prototype capillary pressure functions are related to each other, namely either by direct proportionality (Equation 15a) or by general linear transformation (Equation 15b). The physical significance of these two types of correlation will be examined with the help of the concept by which the capillary pressure corresponding to any given water saturation may be considered as inversely proportional to the hydraulic radius of the pores reached by this water saturation.

BASIC SCALING LAWS

The case where model and prototype capillary pressure functions are directly proportional to each other is illustrated by the curves labeled "Model" and "Reservoir I" in Fig. 1. These curves are such that the ratio, P_{cl}/P'_{cl}, is the same at any one saturation. Accordingly, the pore radii reflected by these two curves are in a constant proportion to each other, meaning that in this case model and prototype have similar pore size distributions. To obtain a physical picture of this situation, one might visualize the porous matrix of the model as an exact enlargement, a blown up replica of the porous matrix of the prototype.

In the light of the above described physical picture it is possible to evaluate the interrelations between the capillary pressure functions, the porosities, and the specific permeabilities applying to model and prototype.

For a porous medium possessing a given pore size distribution it is possible to define a mean hydraulic pore radius, $\bar{r}$, such that

$$k = tf\bar{r}^2 = tf\,(2\sigma\cos\theta/\overline{P}_c)^2 \quad . \quad . \quad . \quad . \quad (28)$$

where t represents a dimensionless textural constant and $\overline{P}_c$, the harmonic average capillary pressure corresponding to the mean hydraulic pore radius. Under conditions of similar pore size distribution, it is apparent that model and prototype are characterized by the same textural constant; furthermore, in this case the ratio of the harmonic averages of capillary pressure is equal to the scale ratio, G, of capillary pressures. Accordingly, the ratio of specific permeabilities may be expressed as:

$$\frac{k}{k'} = \frac{f}{f'}\,\frac{(\sigma\cos\theta)^2}{(\sigma'\cos\theta')^2}\,\frac{\overline{P'_c}^2}{\overline{P}_c^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

It remains to examine the compatibility of Equation 29 with the scaling conditions stipulating that the relative permeability curves be the same for model and prototype. For a given porous medium, i.e., a given pore size distribution, the relative permeability curves should be expected to change according to the contact angle of the fluid system. Therefore, two porous media having similar pore size distributions can be expected to yield the same relative permeability curves only if the contact angle is the same in both cases. Thus, proper scaling on the basis of the considerations advanced so far requires that the contact angle of the fluid systems employed in model and prototype be the same. Accordingly, the interrelation between the permeability and the capillary pressure scale ratios reduces to

$$\frac{k}{k'} = \frac{f}{f'} \cdot \left(\frac{\sigma}{\sigma'}\right)^2 \cdot \left(\frac{\overline{P'_c}}{\overline{P}_c}\right)^2 \quad . \quad . \quad . \quad . \quad (30)$$

This equation, introducing an additional scale ratio (pertaining to the interfacial tensions) but at the same time defining the interdependence between the permeability and capillary pressure scale ratios, must be used in conjunction with Equations 19 in correlating model and prototype parameters.

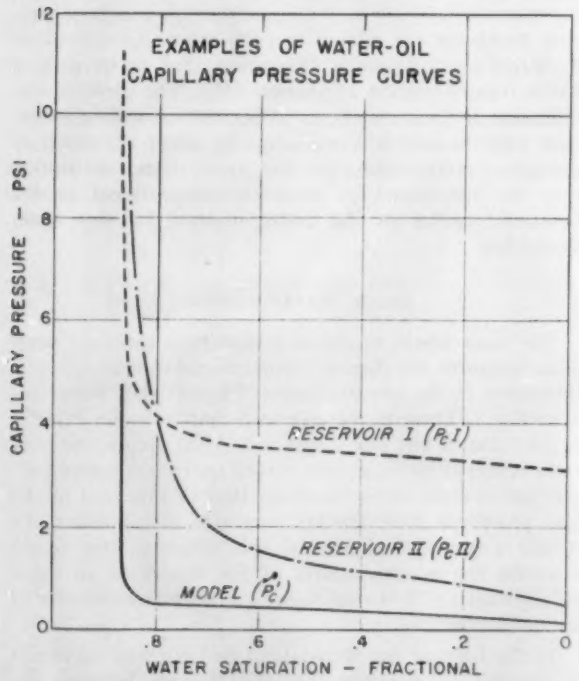

FIG. 1 — MODEL AND PROTOTYPE CAPILLARY PRESSURE FUNCTIONS.

The conditions leading to the establishment of Equations 19 and 30 imply a direct proportionality between the capillary pressures applying to model and prototype. While these equations are somewhat restrictive from the standpoint of practical applications, their compatibility with the physical concepts pertaining to the microbehavior of fluids in porous media has been demonstrated. Therefore, the conditions summarized by Equations 19 and 30 may be qualified as "basic" scaling laws.

GENERALIZED SCALING LAWS

An extension of the basic scaling laws can be established by considering that the correspondence between model and prototype capillary pressure functions is based on a general linear relationship as described by Equation 15b. This situation is illustrated by the curves labeled "Model" and "Reservoir II" in Fig. 1. These two curves are such that the slopes corresponding to any given saturation remain in a constant proportion, G, to each other. Thus both curves have similar shapes. However, since their relative positions are selected arbitrarily by means of the additional scaling parameter, Γ, the ratio $P_{c\text{II}}/P'_c$ will vary throughout the range of saturations. Since the ratio of capillary pressures is inversely proportional to the ratio of corresponding pore radii, it is apparent that in this case the pore size distributions of model and prototype are not similar to each other.

In the case where model and prototype have different pore size distributions, the relationship between their permeabilities, porosities, and capillary pressure functions cannot be defined as exactly as under the assumption of similar pore size distributions. This relationship can, however, be approximated on the basis of a development advanced by Purcell.[5] According to this theoretical development, supported by experimental evidence, the specific permeability can be expressed as:

$$k = \frac{(\sigma\cos\theta)^2}{2.10^4}\,\tau f \int_o^1 dS/P_c^2 \quad . \quad . \quad . \quad . \quad (31)$$

Having selected the capillary pressure curves in accordance with Equation 15b, the relation between model and prototype permeabilities is then determined as:

$$\frac{k}{k'} = \frac{f}{f'} \cdot \left(\frac{\sigma\cos\theta}{\sigma'\cos\theta'}\right)^2 \frac{\int_o^1 dS/P_c^2}{\int_o^1 dS/P'^2_c} \quad . \quad . \quad (32)^*$$

Again, it is necessary to examine the compatibility of the relationship between permeabilities and capillary pressure functions (Equation 32) with the scaling condition stipulating that the relative permeability curves be the same for model and prototype. Since model and prototype are now assumed to have dissimilar pore size distributions, their relative permeability diagrams should be expected to differ from each other if the contact angle is the same for both systems. However, general experimental evidence indicates that for a given porous me-

*In the derivation of Equation 32 it is implied that although model and prototype have different pore size distributions their "lithology factor," τ, is the same. Since the experimental evidence to date indicates that the lithology factor does not deviate excessively from an average value of about 0.25, the above assumption is believed to be admissible for purposes of first approximation.

dium the relative permeability functions can be changed appreciably by changing the contact angle. It is, therefore, reasonable to consider that in the case of two media (model and prototype) having different pore size distributions, there exists a set of contact angle values for which both media will yield the same relative permeability curves. Thus in the formulation of Equation 32, it is implied that the ratio of contact angles is selected in such a manner as to produce the same relative permeability curves in model and prototype. Inductive reasoning suggests that the contact angle ratios satisfying this latter condition must be a function of the scale parameters G and Γ, defining the capillary pressure curves for model and prototype. An explicit form of this interrelation has as yet not been established (except for the particular case of $\Gamma = 0$, corresponding to $\theta/\theta' = 1$). Therefore at present, the application of "generalized" scaling laws based on the use of Equation 15b requires that the ratio of contact angles applying to model and prototype be estimated in an empirical manner.

Admittedly, the above procedure introduces some uncertainty in the correlation between model and prototype; but as will be shown in a later discussion, such uncertainty does not represent too serious a limitation in the practical application of the generalized scaling laws. From this latter viewpoint, it is pointed out that a particular virtue of the preceding development is to show that model and prototype do not necessarily have to have similar pore size distributions. Thus, artifically constructed flow models (which usually possess a rather uniform pore size distribution) can be actually considered as representative of natural reservoir materials. In the light of these remarks it is believed that the generalized scaling laws increase the range of applicability and add considerable significance to the results of flow model experiments.

Recapitulation

The system of Equations 19 represents, from a mathematical standpoint, the formulation of the scaling properties of three-dimensional flow systems composed of two incompressible, immiscible fluids subjected to gravity and capillary forces. These mathematical or macroscopic scaling properties must be supplemented by physical considerations, expressed by Equations 30 or 32, regarding the structure of porous media and the micro-behavior of fluids. Equation 30 or Equation 32 must be used in conjunction with Equations 19, according as to whether the pore size distributions of model and prototype are supposed to be similar or dissimilar to each other. It is furthermore implied in all derivations that the relative permeabilities and capillary pressures applying to model and prototype are functions of saturation only.

In addition to the requirements explicitly discussed in the derivations, it is apparent that the initial (boundary) conditions and the succession of operations must be the same for model and prototype. In summary, then, the conditions required for proper modeling of water-oil flow processes can be stated as follows:

1. The model must be constructed in such a manner as to reproduce the prototype geometry (boundaries, well distribution, well penetration).

2. The initial fluid distribution as well as the succession and distribution of operations (water injections and all oil withdrawals) must be the same for model and prototype.

3. The relative permeability functions and the oil-water viscosity ratio must be the same for model and prototype.

4. The capillary pressure functions applying to model and prototype must be related to each other either by direct proportionality:

$$P'_c = P_c/G, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15a)$$

or by general linear transformation:

$$P'_c = P_c/G + \Gamma \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15b)$$

5. If there is direct proportionality between model and prototype capillary pressure functions, (Equation 15a), the pore size distributions are similar and the values of contact angle are the same for model and prototype. The design and operation of the model must then be conducted in accordance with Equations 19 and 30 which may be restated as:

$$\left[q\mu_w/L^2k\triangle\rho\right]_{\text{model}} = \left[q\mu_w/L^2k\triangle\rho\right]_{\text{prototype}} \quad . \quad (33)$$

$$\left[q\mu_w/LkP_c\right]_{\text{model}} = \left[q\mu_w/LkP_c\right]_{\text{prototype}} \quad . \quad . \quad (34)$$

$$\left[kP_c^2/f\sigma^2\right]_{\text{model}} = \left[kP_c^2/f\sigma^2\right]_{\text{prototype}} \quad . \quad . \quad . \quad (35)$$

This set of equations defines the "basic" scaling laws.

6. If there is general linear correlation between model and prototype capillary pressure functions (Equation 15b), the pore size distributions are not similar and the values of contact angle are different for model and prototype. The operation and design of the model must in this case be conducted in accordance with Equations 19 and 32, which may be restated as:

$$\left[q\mu_w/L^2k\triangle\rho\right]_{\text{model}} = \left[q\mu_w/L^2k\triangle\rho\right]_{\text{prototype}} \quad . \quad (33)$$

$$\left[\frac{q\mu_w}{Lk\,\dfrac{dP_c}{dS}}\right]_{\text{model}} = \left[\frac{q\mu_w}{Lk\,\dfrac{dP_c}{dS}}\right]_{\text{prototype}} \quad . \quad (34)'$$

$$\left[k/f(\sigma\cos\theta)^2\int_o^1\frac{dS}{P_c^2}\right]_{\text{model}}$$

$$= \left[k/f(\sigma\cos\theta)^2\int_o^1\frac{dS}{P_c^2}\right]_{\text{prototype}} \quad . \quad . \quad . \quad . \quad . \quad (35)'$$

These latter conditions extending the flexibility of modeling procedures beyond that offered by the basic scaling laws may be qualified as "generalized" scaling laws. In the application of Equation 35′ it is necessary to evaluate empirically a scale ratio of contact angles producing the same relative permeabilities for model and prototype. Thus in using the generalized laws, the scale ratio of permeabilities (and of rates, which are directly affected by the permeability scale ratio) can be defined only within the limits of accuracy to which an appropriate ratio of contact angles can be estimated.

It will be noticed that in the above system of scaling conditions, Equation 33 may be replaced by the equivalent expression:

$$\left[\frac{L\triangle\rho/dP_c}{dS}\right]_{\text{model}} = \left[\frac{L\triangle\rho/dP_c}{dS}\right]_{\text{prototype}} \quad . \quad . \quad (36)$$

Thus the relationship between the scale ratios of dimensions, fluid density differences and capillary pressures is independent of (uncertainties in the evaluation of) the scale ratios of permeabilities and rates.

A model designed and operated in accordance with the above outlined conditions will exhibit a behavior that is in all points similar to that of the prototype. More specifically it can be stated that:

a. The saturation distributions existing in the model and in the prototype are similar at homologous times.
b. The relationship between cumulative water injection or influx and oil recovery observed in the model is the same as that to be expected in the prototype.
c. The pressure distributions existing in the model are similar to those existing in the prototype, the flowing pressure drops in the model being, however, reduced in the same proportion as the derivatives (with respect to saturation) of the capillary pressure functions.
d. The ratio of corresponding operational or homologous times between model and prototype (c.f. Equations 17 and 19) is determined as:

$$T/T' = \frac{f}{f'}\frac{\mu_w}{\mu'_w}\frac{k'}{k}\left(\frac{L}{L'}\right)^2 \cdot \left(\frac{dP'_c}{dS} \Big/ \frac{dP_c}{dS}\right)$$

$$= \frac{f}{f'}\frac{\mu_w}{\mu'_w}\frac{k'}{k}\frac{L}{L'}\frac{\Delta\rho'}{\Delta\rho} \quad \ldots\ldots\ldots\ldots \quad (37)$$

DISCUSSION AND APPLICATIONS

Review of Scaling Analyses

Most formulations of scaling laws presented in the literature of petroleum technology were based on the use of dimensional analysis which requires an implicit or advance knowledge of all the pertinent dimensional, as well as dimensionless, variables influencing the flow processes under consideration. For the sake of clarification and completeness it appears desirable to compare the scaling conditions established by dimensional analysis with those obtained by the present somewhat more explicit mathematical approach.

In the treatment advanced by Leverett et al[1] it is implied that acceleration is a pertinent variable. Considering further that gravitational acceleration is necessarily the same for model and prototype, one of the basic scaling conditions was formulated as:

$$L/T^2 = L'/T'^2.$$

While it is true that the acceleration of gravity is the same for model and prototype, it must be kept in mind that in laminar flow the forces of inertia are negligible so that acceleration is actually not a pertinent variable in regard to the flow processes governed by Darcy's Law.* Thus, in laminar flow processes the relationship between distance and time scale ratios is established merely by stating that during homologous time intervals, a fluid particle must travel homologous distances in model and prototype, as expressed by Equation 17; this then leads to the scaling conditions (Equation 19) which necessarily differ from those proposed by Leverett et al. It is pointed out that the scaling conditions advanced by Leverett et al are not in contradiction with but rather in excess of those actually required for the modeling of laminar flow processes. The requirement of equal accelerations for model and prototype merely corresponds to a supplementary restriction which may be expressed as:

$$(f\mu_w\sqrt{L}/k\Delta\rho)\text{model} = (f\mu_w\sqrt{L}/k\Delta\rho)\text{prototype}$$

The use of this latter condition, in addition to the scaling Equations 33 through 35, decreases the number of independent parameters or scale ratios, and thereby appreciably reduces the scope of the modeling procedures pertaining to fluid flow in porous media.

The succinct analysis established by Engelberts and Klinkenberg[2] applies to linear flow systems and leads to the conclusion that the geometry (defined by length, thickness, and angle of tilt), the viscosity ratio, and the two dimensionless groups:

$$\text{(a)}\ \ \Delta\rho k/V\mu_w \text{ and (b) } L\Delta\rho\sqrt{k}/\sigma\cos\theta$$

must be the same for model and prototype. These conditions are essentially in agreement with the "basic" scaling laws expressed by Equations 33 through 35. By accounting for the relation between total rate of injection and unit flux for model and prototype:

$$\frac{q}{q'} = \frac{VL^2}{V'L'^2} \quad \ldots\ldots\ldots\ldots \quad (16)'$$

a combination of Equations 33, 34, and 35 results in:

$$(\Delta\rho k/V\mu_w)_{\text{model}} = (\Delta\rho k/V\mu_w)_{\text{prototype}} \quad (38)$$

$$(L\Delta\rho\sqrt{k}/f\sigma)_{\text{model}} = (L\Delta\rho\sqrt{k}/f\sigma)_{\text{prototype}} \quad (39)$$

As regards the combination of dimensional quantities, the groups figuring in the above equations are similar to those of Engelberts and Klinkenberg. However, in regard to the role of the dimensionless parameters, the present derivations show that porosity can, and usually should, be considered as a scalable characteristic. On the other hand, the contact angle entering into the group (b), proposed by Engelberts et al, must be the same for model and prototype and, therefore, should not be treated as an independent parameter. In further explanation, it should be pointed out that the treatment of Engelberts and Klinkenberg (as well as that of Leverett et al) implies similar pore size distributions for model and prototype, and that an explicit consideration of dissimilar pore size distributions was not attempted in their analysis.

From the viewpoint of general applicability, an advantage of the present treatment of scaling over those based on dimensional analysis is that it permits specific consideration of the functions currently employed in reservoir engineering to define multiphase flow characteristics. The explicit correlation between model and prototype capillary pressure curves entering into the general scaling equations is believed to be of particular use in evaluating the practical significance of flow model test results. On the other hand the detailed mathematical formulation (c.f. Equations 7 and 8) used to derive the scaling properties of water-oil displacements shows that the present scaling laws are valid only in the case where the relative permeability and capillary pressure functions are independent of rate and fluid viscosity.

Application of Scaling Laws to Simplified Cases — Example

The scaling relations expressed by Equations 33 through 35′ cover the most general situation of a three-dimensional flow system. The scaling properties of less complex systems as encountered in linear or two-dimensional (areal) flow problems, or for situations where capillary or gravitational effects are negligible, can be readily derived from these general equations. In the case where gravity effects are considered to be negligible, the consideration of Equation 34′ together with 35′ is sufficient to define the generalized conditions of scaling. On the other hand, if capillary effects are negligible the conditions of scaling are described by Equations 33 and

*In the description of laminar flow processes in porous media, the "gravitational constant," g, represents merely a conversion factor to express head of fluid in units of pressure (atmospheres).

35′. For flow processes that are influenced neither by gravity nor capillarity, the general scaling conditions reduce to Equation 35′.

For linear flow systems it should be noticed that all pertinent variables such as pressure, partial flow rates of oil and water, and saturation are, by definition, constant at any moment over any one cross section. Accordingly, the analysis of linear flow phenomena can be restricted to the consideration of systems of unit cross-sectional area, and the scaling of linear systems can be performed on the basis of unit flux, v, or w, rather than on the basis of total rate of injection, q.

On the basis of the preceding remarks, it may be verified that for linear, vertical water-oil displacements the generalized scaling conditions reduce to Equations 35′ and 36 in combination with:

$$\frac{w}{w'} = \frac{k}{k'}\frac{L'}{L}\frac{\mu'_w}{\mu_w}\left(\frac{dP_c}{dS}\Big/\frac{dP'_c}{dS}\right) \quad . \quad . \quad . \quad . \quad (40)$$

which results in the following ratio of homologous operational times:

$$T/T' = \frac{L}{L'}\frac{f}{f'}\frac{w'}{w}\ (*) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

A numerical example illustrating the application of the above scaling relations to the modeling of a bottom water drive in a high relief reservoir is summarized in Table 1. The model considered for this example consists of a 2-ft long dri-filmed alundum core having a water-oil capillary pressure curve as shown in Fig. 1. The other characteristics of the model and of the fluid system employed are presented in Table 1 together with those of hypothetical reservoirs simulated by this model. The characteristics of reservoir I are derived by application of the basic scaling laws and those of reservoir II by application of the generalized scaling laws. The capillary pressure curves assumed for both these reservoirs are shown in Fig. 1.

Examination of Table 1 and Fig. 1 shows that the characteristics of both reservoirs simulated by the model of this example definitely fall within the range of practical conditions. However, reservoir II corresponds to a higher permeability, greater closure and a more realistic capillary pressure curve. This, then, illustrates the greater flexibility of the generalized scaling laws as compared to the basic scaling laws which were used to derive the characteristics of reservoir I.

TABLE 1 — EXAMPLE OF CORRELATIONS BETWEEN MODEL AND PROTOTYPE CHARACTERISTICS

	Model	Reservoir I (by application of "basic" scaling laws)	Reservoir II (by application of "generalized" scaling laws)
Water-Oil Density Difference	0.5 gm/cc	0.2 gm/cc	0.2 gm/cc
Capillary Pressure	P'_c	$P_{cI} = 10\ P'_c$	$P_{cII} = 50\ P'_c = 16.9$ psi
Height or Closure	2 ft	50 ft	250 ft
Oil Viscosity	3.6 cp	1.2 cp	1.2 cp
Water Viscosity	1.8 cp	0.6 cp	0.6 cp
Interfacial Tension	25 dyn/cm	30 dyn/cm	30 dyn/cm
Contact Angle (in oil phase)	0°	0°	25° to 65°
Porosity	38%	19%	25%
Permeability	7,200 md	52 md	312 to 1,560 md Average: 700 md
Scale Ratio of Water Influx Rates		$w/w' = .0087$	$w/w' = .052$ to .26 Average: .115
Scale Ratio of Times		$T/T' = 1440$	$T/T' = 317$ to 1585 Average: 710

*For linear, horizontal water-oil displacements, in which gravity effects are considered to be negligible, the generalized scaling laws reduce to Equations 35′, 40, and 41.

It will be noticed that the scale ratios of permeability, rate of water influx and operational times applying to reservoir II are not exactly defined, but are merely indicated within a certain range. This illustrates the uncertainties associated with the application of the generalized scaling laws.

Since in this example the model and reservoir II have dissimilar pore size distributions, a contact angle had to be estimated for reservoir II which would produce the same relative permeability functions as those applying to the model. While the experimental evidence to date is not sufficient to provide a reliable basis for carrying out such an estimation, it appears reasonable to assume that the desired value of contact angle will be between the limits of 25° and 65°. Accordingly, by application of Equations 35′, 40, and 41, only "probable" average values can be assigned to the scale ratios of permeability, rate of water influx and operational time. It is seen that these scale ratios can possibly deviate from their respective average values by a factor of approximately 2.2. Thus, while the use of the generalized scaling laws does not allow exact determination of the permeability, rate and time scale ratios, it permits the definition of their order of magnitude.

Principles of Application

The application of the scaling laws requires consideration of porous media having different specific permeabilities and porosities but possessing identical relative permeability functions and similarly shaped capillary pressure curves. In practice such a situation is not likely to occur, and in most cases it may be impossible to find a suitable material for the construction of a model permitting quantitative scaling of a flow process occurring in a given reservoir. However, valid information of great practical utility can be obtained by means of model studies scaled and interpreted on the basis of a reverse or "synthetic" approach. This approach consists of using the scaling equations for extrapolating model data to hypothetical reservoirs that would have the same relative permeability curves as the model material and capillary pressure curves that are similar to those of the model.

The reproduction of the relative permeabilities and the similarity of capillary pressure functions represent definite limitations in the application of the above extrapolation procedure. Furthermore, if it is desired to make use of the "generalized" scaling laws, the scale ratios of permeability and operational time can only be approximated. However, the sizes, the absolute values of capillary pressure (i.e., the position of the capillary pressure curves), and the order of magnitude of the specific permeabilities corresponding to the hypothetical, extrapolated reservoirs simulated by a given model can be selected with a considerable degree of liberty (c.f. numerical example). Therefore, model tests performed with two or three different materials, corresponding to different, limiting, types of relative permeability and capillary pressure diagrams, should permit the study of water-oil flow processes for a wide range of reservoir conditions. The behavior of a specific reservoir could then be estimated by fitting or interpolating the characteristics of this reservoir into the range of conditions covered by the experimental model studies.

ACKNOWLEDGMENT

The author wishes to thank The Carter Oil Co. for permission to publish this paper.

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NOMENCLATURE

Subscripts o and w pertain to oil and water, respectively. Ordinary symbols refer to prototype, primed symbols to model. Corresponding variables for prototype and model must be expressed in the same units.

S: Water saturation (dimensionless fraction)

x, y, z: Spatial coordinates (cm)

T: Time (sec)

f: Porosity (dimensionless fraction)

k: Specific permeability (darcies)

k_{ro}, k_{rw}: Relative permeabilities to oil and water (dimensionless functions of saturation)

μ_o, μ_w: Viscosities of oil and water (cp)

p_o, p_w: Pressures in oil and water (atm)

P_c: Capillary pressure, function of saturation (atm)

V_o, V_w: Unit flux for oil and water (rate of flow per unit cross-sectional area in cc/cm²/sec)

$V = V_o + V_w$: Total, two-phase unit flux (cc/cm²/sec)

$u = u_o + u_w$
$v = v_o + v_w$
$w = w_o + w_w$: Components along axes of coordinates of two-phase unit flux (cc/cm²/sec)

ρ_o, ρ_w: Densities of oil and water (gm/cm³)

$\Delta\rho$: Density difference between water and oil (gm/cm³)

g: Gravitational conversion factor (cm² atm/gm)

$\phi = \left(1 + \frac{k_{ro}}{k_{rw}}\frac{\mu_w}{\mu_o}\right)^{-1}$: Dimensionless function of saturation

$\psi = k_{ro}\,\phi$: Dimensionless function of saturation

L, L': Principal or corresponding dimensions for prototype and model (cm)

q, q': Total rates of water injection or influx (equal to total rates of fluid withdrawal) for prototype and model (cc/sec)

Q, Q': Cumulative injection or influx for prototype and model (pore vol.)

α: Dimensionless shape factor defining prototype and model pore volumes on the basis of their principal dimensions, namely:
Prototype Vol. $= L^3 \cdot \alpha \cdot f$
Model Vol. $= L'^3 \cdot \alpha \cdot f'$

σ: Water-oil interfacial tension (dyn/cm)

θ: Water-oil-solid contact angle (dimensionless)

τ: Lithology factor (dimensionless)

t: Textural constant (dimensionless)

$A = L/L'$: Scale ratio of dimensions

$B = q/q'$: Scale ratio of total injection or production rates

$C = f/f'$: Scale ratio of porosities

$D = k/k'$: Scale ratio of permeabilities

$E = \Delta\rho/\Delta\rho'$: Scale ratio of fluid density differences

$F = \mu_o/\mu'_o = \mu_w/\mu'_w$: Scale ratio of fluid viscosities

$G = P_c/P_c'$: Scale ratio of capillary pressure functions

Γ: Additional capillary pressure scaling parameter (atm) ★★★

SOLUBILITY STUDIES on HIGH MOLECULAR WEIGHT PARAFFIN HYDROCARBONS OBTAINED from PETROLEUM ROD WAXES

C. C. NATHAN | THE TEXAS CO. BELLAIRE, TEX.

T. P. 4122

ABSTRACT

Data are presented on the physical properties of five waxes obtained from fields in Texas and Louisiana in which "paraffin" troubles are being experienced. The crude paraffin was fractionated into three components, soluble in cold acetone, soluble in boiling acetone, and insoluble in boiling acetone. The acetone insoluble fraction was found to consist essentially of straight chain paraffin hydrocarbons in the molecular weight range 525 to 700.

Solubilities of the purified high molecular weight paraffins were determined in a number of solvents. It was found that in hydrocarbon solvents, including crude oil, solubilities could be calculated satisfactorily by use of ideal solubility relations. In chlorinated, and oxygenated solvents, large deviations from ideal behavior were observed. These deviations could be partially correlated with the internal pressure of the solvent.

INTRODUCTION

A problem encountered in many producing oil fields is that of "paraffin" deposition. The problem refers to the deposition of material from the crude oil onto tubing, pumping rods, flow lines, or other material contacted by the crude. This problem has been recognized for nearly a hundred years, and numerous investigations have been reported on its causes and prevention or alleviation. One of the more comprehensive of such investigations was published by Reistle[1] in 1932. A few of the salient findings of his report are briefly as follows:

The term "paraffin" as used to describe this problem refers to the deposit of carbonaceous material which is not soluble or dispersible by the crude oil under the conditions where deposition occurs. The "paraffin" normally consists of high molecular weight paraffin hydrocarbons, both straight chain and branched, resins and asphaltic materials of undetermined nature, occluded oil and water, and possibly sand. In consistency, the deposit may vary from a soft, sticky material, to one which is hard and brittle. Deposits are usually black, although lighter colors are sometimes observed.

Under the conditions of temperature, pressure, and crude oil composition occurring in the underground reservoir, the paraffin is in suspension or solution in the crude. As the oil flows to the surface, there is generally a reduction of temperature, pressure, and the amount of dissolved gases contained in the oil. Reduction of temperature and gas break-out were shown by Reistle to be factors causing reduced solubility of the paraffin in the crude. Thus, as the crude containing paraffin rises to the surface and flows to storage tanks at atmospheric temperature, the solubility of the paraffin may be exceeded. Deposition will begin at the point in the system where the temperature of the system falls below its cloud point, and continue as long as there is a further drop in the solution power of the crude for the paraffin. The severity of the deposition as well as the location of the bulk of the deposition, i.e., in subsurface or surface equipment, will depend on the amount of paraffin originally in the crude, the manner in which pressure and temperature of the crude

[1]References given at end of paper.

Manuscript received in Petroleum Branch office on April 21, 1955.

are reduced, and other properties of the crude and of the paraffin.

As was shown by Reistle, the melting point of the paraffin is the principle factor influencing the solubility of a paraffin in a given solvent, the solubility decreasing sharply with increased melting point, as would be expected. For hydrocarbon solvents, the main factor which influenced solvent power was shown by Reistle to be the API gravity of the solvent, solvents of high API gravity (or lower specific gravity) being superior paraffin solvents.

OBJECTIVE OF THE PRESENT WORK

It was thought that the various factors described above could be embodied in a single relation on a quantitative basis, thus making it possible to predict the solubility of any paraffin in any crude or solvent at any temperature. If it can be assumed that the system, paraffin-crude oil (or other solvent) is an ideal solution, then the familiar relation can be used:[3]

$$ln\, N_2 = -\frac{\triangle H_f}{R}(1/T - 1/T_m) \quad . \quad . \quad . \quad (1)$$

$$\text{also } N_2 = \frac{w_2/M_2}{w_2/M_2 + w_1/M_1} = \frac{w_2/M_2}{w_1/M_1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

since for dilute solutions $w_2/M_2 \ll w_1/M_1$.
Combining Equations 1 and 2 and converting to common logarithms, we obtain

$$\log W_2 = \frac{-\triangle H_f}{2.303\,R}(1/T - 1/T_m) + \log M_2 + \log W_1 - \log M_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The last equation may be verified by determining cloud points of solutions of known weights of paraffin in solvents of known molecular weight. If the melting point and heat of fusion of the paraffin are known, it is then possible to calculate the amount of paraffin which would be in solution at the measured cloud point. The equation then may be verified by comparing the observed and calculated values of the paraffin solubility at the cloud point temperature.

VERIFICATION OF THE EQUATION

Determination of T_m, M_2, and $\triangle H_f$

As stated previously, the paraffins obtained from field deposits are complex mixtures of hydrocarbons and other materials. These materials have a wide range of melting points, solubilities, etc. It was decided to attempt a partial separation and purification of the samples received. Each sample of paraffin was separated into three fractions, by successive treatments with hot acetone. One hundred gm of the paraffin was melted and poured into 300 ml of acetone, and refluxed for one hour.

The boiling acetone solution was then decanted from the undissolved paraffin. The undissolved fraction was again treated with acetone, as many times as were necessary to remove all material soluble in boiling acetone. Material not soluble in hot acetone will be described as "hard wax." The acetone solutions were combined and cooled at 10° C. Any material which precipitated on cooling of the acetone is described as "soft wax." The acetone, filtered of soft wax, was then evaporated and the residue, soluble in cold acetone, is described as "oil."

Further purification of the hard waxes was effected by standard purification methods employing recrystallization from suitable solvents and by urea extractive crystallization.[3] The final products were white, flaky waxes of fairly sharp melting points.

Table 1 lists the properties of the five waxes investigated. The melting points of the crude paraffins were determined from cooling curves of the molten paraffins. It will be observed that the melting points of the crude paraffins vary over a rather wide range, as do the melting points of the pure paraffins prepared from them. The crude paraffins all contain about the same proportion of oil (23 to 36 per cent). The percentage of soft wax generally falls and the percentage of hard wax rises with the melting point of the crude paraffin. The proportion of normal paraffins in the hard wax is uniformly high at 70 per cent or greater, while the proportion of hard wax in the crude paraffin is 50 per cent or more. Thus, the proportion of high molecular weight normal paraffin hydrocarbons in the crude paraffin is about 40 to 60 per cent, and this fraction has a melting point range of only 2° C.

TABLE 1

Paraffin	A	B	C	D	E
M.P. of Crude Paraffin, °F	152	153	176	176	184
°C	66.5	67	80	80	84.5
Per Cent Oil	24	30	30	36	23
Per Cent Soft Wax	26	17	7.5	13	2.5
Per Cent Hard Wax	49	52.5	62	51.5	74.5
M.P. of Hard Wax, °C	73.5-77	80.5-81.5	89-91	88-91	85.5-89
Yield of n-Paraffins from Hard Wax, %	85	71.5	91.5	95	78
Yield of n-Paraffins from Crude Wax, %	42	38	57	48	58
M.P. of Pure Wax, °C	76-78	79.5-82	89.5-90	89-90	90-92
S.G. of Pure Wax, 77° F	0.961	0.965	0.949	.....	0.974

In the calculation of the solubilities of the natural paraffins in their associated crudes, the hard wax purified fraction has been considered to be the key fraction, since its solubility is the least of the three fractions prepared. Furthermore, there can be little error introduced by this assumption, since the hard wax fraction is in every case 50 per cent or more of the total paraffin deposit.

The average molecular weight of the purified hydrocarbon can be determined as a function of its melting point using the data of Van Nes and Van Westen[4], which function is reproduced in Fig. 1 as a plot of the number of carbon atoms, n, vs the melting point of the normal paraffin. The latent heat of fusion was determined by measuring the solubilities of the purified waxes in heptane at several temperatures. Equation 1 may be written:

$$ln\, N_2 = \frac{\triangle H_f}{R\,T_m} - \frac{\triangle H_f}{R\,T} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

A plot of $ln\ N_2$ vs $1/T$ gives a straight line whose slope is $-\triangle H_f/R$ and whose intercept at $N_2 = 1.000$ equals $1/T_m$. Fig. 2 gives the solubilities of the five waxes in heptane, as well as the solubility of dotriacontane for comparison. It is unfortunate that the extrapolations had to be extended so far from lower temperatures because of insufficient quantities of wax to determine solubilities at temperatures approaching the melting points. However, it is of interest to note that

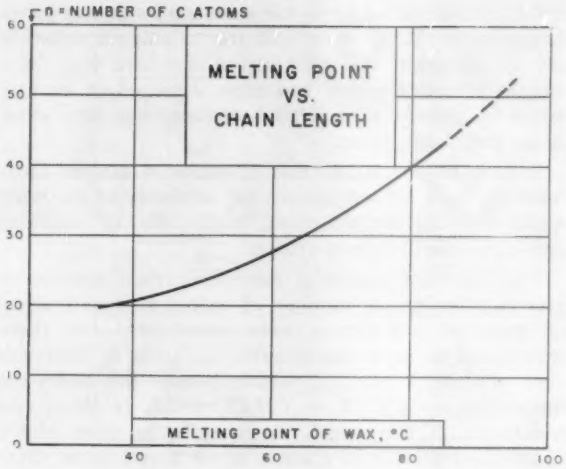

FIG. 1 — PLOT OF THE NUMBER OF CARBON ATOMS, N, VS THE MELTING POINT OF THE NORMAL PARAFFIN.[4]

the extrapolated lines do intersect the point $N_2 = 1.000$ at temperatures which are equal to the wax melting points within the limit of experimental error of our measurements and melting point determinations. Since we do not have measured values at elevated temperatures, the possibility of transition of the waxes at temperatures below the melting point as described by Hildebrand[3] is not ruled out. However, the error introduced in assuming that the transition temperature and melting temperature are equal, i.e., that there is no transition, is probably negligible for the paraffin waxes of high melting point, since the two temperatures are known to approach as the molecular weight of the wax rises. Thus, Muller[6] reports for C_{20} a m.p. of 66.6° C, and a transition point 9° C lower; for C_{24} a m.p. of 72.8, transition point 5° C lower; and for C_{44} a m.p. of 86.4, transition point 0.6° C lower. Seger[7] presents similar data and predicts that the transition point and melting point will become equal for paraffins of 45 to 46 carbon atoms and more.

In attempting to correlate the experimental solubility data, a compilation was made of all of the literature values of heats of fusion of normal paraffins. The entropies of fusion per mole and per carbon atom were then calculated. These data are listed in Table 2. It will be seen that the entropy per carbon atom lies between two and three entropy units for all paraffins above butane. The even-odd sequence is obvious up to 20 carbon atoms. A plot of the entropy per carbon atom vs the number of carbons (Fig. 3) indicates that the odd-even effect eventually disappears, and that for high molecular weight normal paraffins, a constant value of about 2 e.u. or (R e.u.) per carbon atom is attained. Hildebrand[5] and Glasstone[8] give theoretical reasons for expecting such a value. The value of 1.60 e.u. per carbon atom derived from the data of Meyer and van der Wyk[9] probably should not be included in this table, since their solubility data for C_{60} H_{122} are given in decalin, which is an abnormal solvent, as will be pointed out later in this paper.

EFFECT OF SOLVENT, DETERMINATION OF M_2

The equation was verified in a number of hydrocarbon and nonhydrocarbon solvents. Table 3 presents the data, listing the ratio of measured to calculated

TABLE 2 — LATENT HEAT AND ENTROPY OF FUSION FOR NORMAL PARAFFIN HYDROCARBONS

n No. of C atoms	t m.p. °C	T m.p. °K	ΔH_f K cal/mole	$\Delta S_f = \Delta H_f/T$ cal/mole/°	$\frac{\Delta S_f}{n}$	Notes
1	−182.6	90	0.232	2.37	2.37	1
2	−172	101	0.666	6.59	3.30	1
3						
4	−135	138	1.044	7.57	1.89	1
5	−131.5	141.5	1.998	14.10	2.82	1
6	− 94	179	3.065	17.12	2.86	1
7	− 90.6	183	3.370	16.76	2.39	1
8	− 56.5	217	4.935	22.7	2.84	1
9	− 54	219	3.70	16.9	1.88	5
10	− 32	241	6.850	28.5	2.85	1
11	− 26.5	247	5.320	21.5	1.96	1
12	− 12	261	8.710	33.4	2.78	1
13	− 5	268	6.84	25.5	1.96	5
14	+ 6	279	11.04	39.5	2.82	5
15	10	283	8.31	29.4	1.96	5
16	18	291	12.39	42.55	2.66	5
17	22	295	9.65	32.70	1.93	5
18	28	301	14.80	49.20	2.73	5
20	38	311	14.68	47.2	2.36	1
23.5	50	323	18.72	58.0	2.95	2
25	54	327	18.88	57.8	2.31	1
32	70	343	22.9	66.8	2.08	1
37.3[a]	78	351	24.3	69.3	1.86	3
42.2[b]	83	356	29.3	82.4	1.95	3
47.0[c]	89	362	33.4	92.1	1.96	3
48.0[d]	90	363	34.5	95.0	1.98	3
49.0[e]	91	364	34.5	94.8	1.93	3
60	99.5	372.5	44.0	108.1	1.80	4

[a] Purified Paraffin—A
[b] Purified Paraffin—B
[c] Purified Paraffin—C
[d] Purified Paraffin—D
[e] Purified Paraffin—E

(1) Literature values of measured heats of fusion.
(2) From solubility vs temperature of commercial paraffin wax in naphtha, data of Work & Berne-Allen, *Ind. Eng. Chem.*, 30, 806 (1938).
(3) This work from solubility vs temperature in n-heptane.
(4) From solubility vs temperature in decalin — Meyer and van der Wyk — *Helv. Chem. Acta.*, p. 1313 (1937).
(5) From cryoscopic constants, Table 14-3 of Rossini, Mair & Streiff, "Hydrocarbons from Petroleum."

solubilities by Equation 3. For each solvent, the solubility of at least one of the purified waxes was determined over a temperature range sufficient to give a 10 to 30-fold range in concentration of the dissolved wax, i.e., from 0.05 to 3.2 gm wax per mole of solvent. The molecular weight of the solvent for solvents consisting of crude oil or any fractions obtained by distillation of crudes was determined from the specific gravity and average boiling point of the solvent as described by Nelson.[10] The temperature range of the solubility measurements was from 5° C to 55° C depending on the solvent in use. The data of Table 3 give the ratio of calculated to measured solubilities at 35° C. In some cases, these data were extrapolated

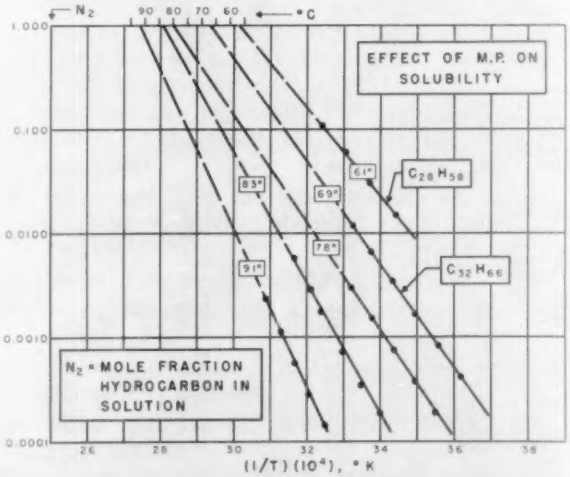

FIG. 2 — SOLUBILITIES OF FIVE WAXES IN HEPTANE, COMPARED WITH SOLUBILITY OF DOTRIACONTANE.

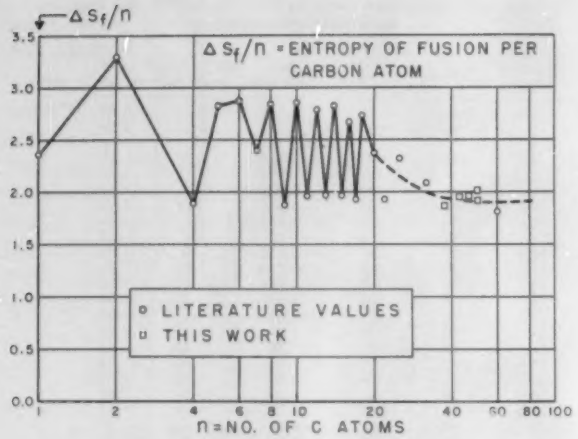

FIG. 3 — PLOT OF ENTROPY PER CARBON ATOM VS NUMBER OF CARBONS.

from higher or lower temperatures, for very abnormal solvents.

As can be seen from Table 3, most hydrocarbon solvents give solubilities which are not different from those calculated by Equation 4 by more than a factor of 3. Decalin is the hydrocarbon with the maximum deviation. Pure hydrocarbons, whether aliphatic, aromatic or olefinic give values close to theoretical. The solubilities of naphtha and kerosene fractions derived from crude oils are generally greater than calculated by a factor of 2 to 3. In only one case, was it possible to measure the solubility of the wax in its parent crude, since cloud points could not be determined with the existing equipment in the dark, black, crudes. One crude was sufficiently light to measure cloud points in it. This crude contains about 2½ per cent of soft waxes melting at approximately 55° C. It was found that the solubility of the hard wax in this crude was very close to the calculated value at a temperature of

TABLE 3 — EFFECT OF VARIOUS SOLVENTS ON SOLUBILITY OF HIGH M. W. WAXES IN TEMPERATURE RANGE 15-55° C

Solvent	Solubility Factor (Heptane = 1.00)	Internal Pressure cal/cc	Temperature Increase to Double Solubility °C
Hexane	1.41	52.6	4.3
Heptane	1.00	55.5	3.8
C_{16}	0.55	63.4	3.7
Mineral Oil MW = 380	0.56	.....	4.6
Naphtha MW = 110	2.2	.....	4.1
Kerosene MW = 152	2.4	.....	4.1
Gas Oil MW = 225	0.92	.....	4.2
Crude Oil MW = 220	1.00	.....	4.1
Benzene	0.87	84.0	3.7
Toluene	1.63	79.0	3.4
Xylene	1.59	80.5	4.0
Styrene	0.81	86.5	4.0
Tetralin	1.20	84.0	.....
Decalin	3.7	47.3	.....
CH_2Cl_2	0.46	94.0	.....
$CHCl_3$	1.61	86.5	4.1
CCl_4	4.15	74.7	4.3
$CH_2Cl - CH_2Cl$	0.017	96.1	3.0
$CCl_3 - CH_3$	1.00	72.2	4.2
$CCl_2 = CCl_2$	3.00	94.0	4.2
$CHCl = CCl_2$	3.00	90.5	4.2
$CHCl_2 - CHCl_2$	0.17	72.0	4.0
$CCl_3 - CHCl_2$	1.20	65.5	4.3
$CHCl_2 - CH_2Cl$	0.12	88.2	4.6
CS_2	4.7 @ 25°C 11.2 @ 35°C	100.0	3.3 (25°C to 35°C)
$CH_3 - CO - CH_3$	0.02	98.6	.....

Note: Solubility in heptane is approximately 1.1 — 1.5 times theoretical value for these waxes.

50° C, but deviated from the calculated value at lower temperatures, being only half the calculated value at 25° C. However, the solubility of the hard wax, in a sample of crude which had been dewaxed of its soft waxes by treatment with cold acetone, was very close to the calculated value.

It may be concluded that Equation 4 can be satisfactorily used for calculating the solubility of the hard waxes in pure hydrocarbons, crude oils, or fractions derived by distillation of crudes.

The situation regarding nonhydrocarbon solvents is greatly different. A number of chlorinated derivatives of methane and ethane were investigated and there was found to be a considerable variation in their solvent powers, from CCl_4, which is over five times the theoretical, to $CH_2Cl - CH_2Cl$, which is about one hundredth of theoretical. In general, the more highly chlorinated solvent in a series is the best solvent. Oxygenated solvents such as acetone and ethanol were found to be very poor, while carbon disulfide was found to be the best of all solvents investigated.

When the internal pressure of the solvent at 25° C was plotted against the solubility factor at 35° C, the data shown in Fig. 4 were obtained. The internal pressure is defined as the heat of vaporization per cc of solvent. Data were obtained from Hildebrand's *Solubility of Non-electrolytes*, where listed by him. Other values were calculated from vapor pressure-temperature data to obtain latent heats of vaporization, and handbook values of molar volumes. It will be observed that there is a clear relation between the solubility factor and the internal pressure, the solubility factor increasing as the internal pressure decreases. The three chlorinated methanes fall on one line, and the six chlorinated ethanes on another parallel line. The two chlorinated ethylenes lie near the second line.

Aliphatic hydrocarbons including decalin are grouped together on a third line, and aromatic hydrocarbons including tetralin are on a fourth. The slopes of the four lines are parallel, with considerable uncertainty present in the value of the last two lines, since the solubility factors do not differ appreciably from unity for any of the hydrocarbons except decalin. The relation of solubility decreasing with internal pressure of the solvent is in line with Hildebrand's findings. It will be noted that the internal pressures of acetone and carbon disulfide are the highest of any of the solvents we report. Yet acetone is the poorest solvent plotted, and carbon disulfide the best.

EFFECT OF SOLUTION TEMPERATURE AND WAX MELTING POINT

It can be seen from Equation 1 that for equal molar solubilities any increase in the melting point of the wax must be offset by an equal increase in the solution temperature, i.e., the solubility at any temperature is less the higher the melting point of the wax. On a weight basis, the wax solubility does not drop off as sharply with its melting point, since the molecular weight of the wax also rises with its melting point as shown in Fig. 1, somewhat compensating for the decreased molar solubility. Experimental solubilities for five of the waxes in heptane at 35°C are tabulated below in grams per mole of solvent. Two pure paraffins ($nC_{28}H_{58}$ and $nC_{32}H_{66}$) are also included for comparison.

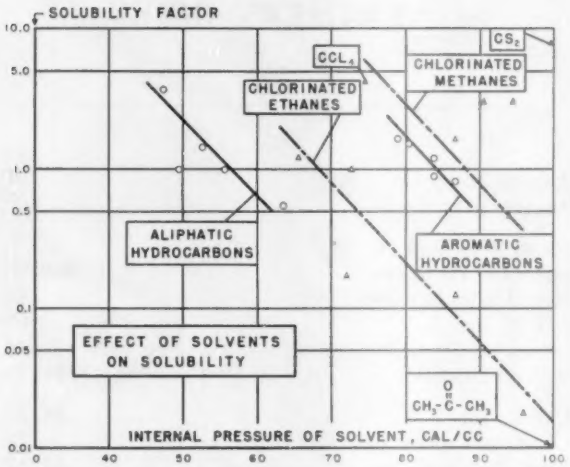

FIG. 4 — PLOT OF INTERNAL PRESSURE FOR THE SOLVENT AT 25° C AGAINST THE SOLUBILITY FACTOR AT 35° C.

The calculated and observed mole fractions solute as well as the heats of fusion obtained from solubility vs temperature plots are also listed. It will be noted that an increase in the melting point of the wax of 13°C results in a 40-fold decrease in the observed solubility on a weight basis, or a 50-fold decrease on a molar basis. This is at 35°C. At higher temperatures, the ratios are less, because of the steeper slope of the plots for the higher melting point waxes. The calculated temperature coefficients are proportional to the heats of fusion, hence the slopes of the highest (91° m.p.) wax and the lowest (78° m.p.) are in the ratio of their heats of fusion = 34.5/24.3 = 1.42. We may thus calculate from Equation 4 that a temperature rise of 3.6° is required to double the solubility of the 91° wax and of 5.1° to double that of the 78° wax at 25°C. Corresponding figures at 50°C are 4.2 and 6.0°C, respectively. Table 3 lists the solubility temperature coefficients for the various waxes in a number of solvents. The average value of the coefficient for a particular wax in a given solvent in the temperature range utilized was calculated and is listed. The temperature range was from 15° to 55°C.

It can be seen from the data of Table 3 that normal solvents give solubility-temperature coefficients in close agreement with the theoretical calculations. Thus, the coefficients in heptane for the 91° and 78° wax are 4.9° and 3.7°. These are close to the calculated values at 25° listed above. Abnormal solvents give coefficients which do not agree with the calculated values, as will be observed for CS_2 (solubility factor 11.2 at 35°C, and solubility-temperature coefficient —3.3°C), and for $CHCl_2$-$CHCl_2$ (solubility factor —0.05, temperature coefficient —3.0).

TABLE 4 — MEASURED AND CALCULATED SOLUBILITIES OF NORMAL PARAFFINS IN HEPTANE AT 35° C

M. P. of Wax	Mol Wt.	Solubility, gm	Measured Mole Fraction	ΔH_f	Calculated Mole Fraction
78° C	525	3.6	0.0068	24.3	0.0059
83	595	0.85	0.00143	29.3	0.0010
89	660	0.165	0.00025	33.4	0.00020
90	675	0.105	0.00015	34.5	0.00013
91	690	0.095	0.00014	34.5	0.00011
69 (Dicetyl)	452	13.4	0.029	22.9*	0.017*
61 (Octacosane)	394	17.3	0.042	21.1*	0.105*
				19.8**	0.066**

*Calculated from solubility vs temperature measurements.
**Calculated on basis of $\Delta H_f = n R T_m$.

CONCLUSIONS

Solubilities of purified high molecular weight paraffins were determined in a number of solvents. It was found that in hydrocarbon solvents, including crude oil, solubilities could be calculated satisfactorily by use of ideal solubility relations. In chlorinated, and oxygenated solvents, large deviations from ideal behavior were observed. These deviations could be partially correlated with the internal pressure of the solvent.

The solubilities of the purified waxes in heptane closely approached ideality. Heats and entropies of fusion were calculated from the slopes of the temperature solubility plots. These values were compared with literature values for other straight chain paraffins, and the conclusion drawn that the molar entropy of fusion per carbon atom is constant and equal to R calories per degree for high molecular weight normal paraffins.

ACKNOWLEDGMENT

The author wishes to express his thanks to the management of The Texas Co. for granting permission to release this paper.

NOMENCLATURE

ΔH_f	Heat of fusion of solute, cal/mole
M_1	Molecular weight of solvent, gm
M_2	Molecular weight of solute, gm
N_1	Mole fraction solvent
N_2	Mole fraction solute
n	Number of carbon atoms per hydrocarbon molecule
R	Gas constant = 1.987 cal/mole/°K
ΔS_f	Entropy of fusion of solute, cal/mole/°K
T	Temperature, °K
T_m	Melting point of solute, °K
t_m	Melting point of solute, °C

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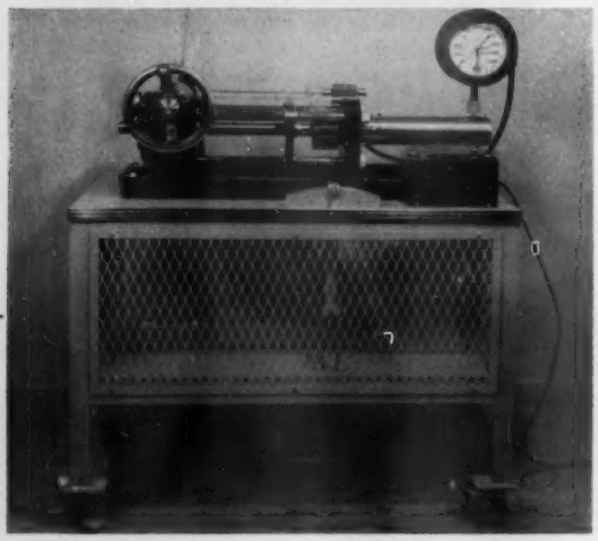

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TO: THE READER

The following Technical Bulletins have been compiled, produced, and presented by some of the manufacturing and service organizations which serve you, as a compliment to your continuous interest in technical information and data. We believe that your interest is especially keen at this time of the year when you are about to gather with fellow members of your profession to review the industry's progress and discuss its technical future. Many of the problems under discussion at the Fall Meeting will be directly influenced by the equipment and service organizations which serve the oil industry.

We believe you will find these bulletins useful and interesting, and well worth adding to your technical data files.

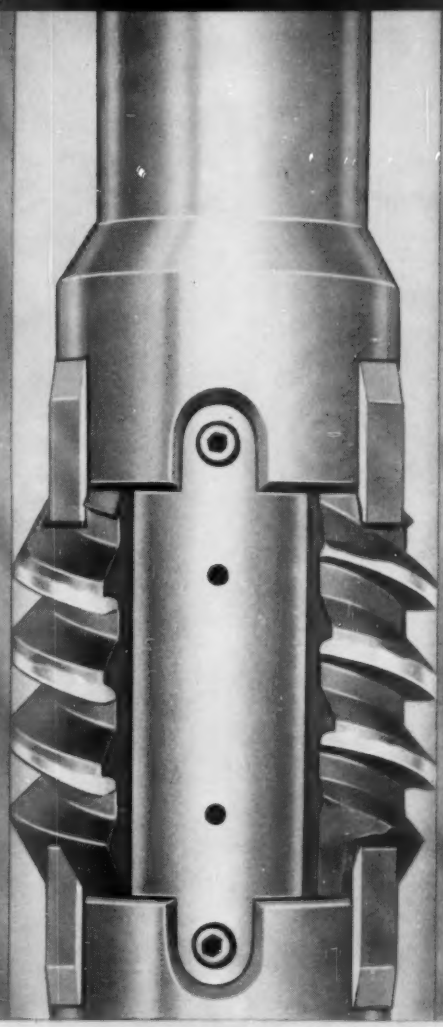
MAURI BRATT
Advertising Manager

TECHNICAL BULLETIN SECTION

Featuring the Equipment and Service Companies
Who Serve the Petroleum Engineering Profession

Photograph through courtesy of Humble Oil & Refining Co

30th Annual Petroleum Branch Fall Meeting
The Roosevelt Hotel, New Orleans, Oct. 2-5, 1955



CAN YOU AFFORD *Not* to scrape your casing ...*the Baker way?*

You can't buy insurance for each job—so do the next best thing . . . keep your casing clean with the . . .

BAKER

This is just another way of asking "CAN YOU AFFORD THE EXPENSE OF DOWN-HOLE EQUIPMENT FAILURES?" The unretouched photograph at the above left provides visual proof of how casing neglect can cause even the best pack-off tool to fail.

In this case the pack-off tool set and packed-off perfectly—but the casing ID failed to do its part. Notice the cracks in the cement sheath in the area where the Packing Element was packed-off. *These cracks allowed the fluid under pressure to by-pass, even though the tool was securely set and completely packed-off.*

The Baker Roto-Vert Casing Scraper, which can be run on tubing, drill pipe or wire line, completely removes cement sheath and other obstructions such as perforation burrs and imbedded bullets—prepares the casing ID for subsequent work with pack-off tools. Remember, the condition of your casing ID is just as important to the successful operation of pack-off tools as the condition of a valve seat is to the operation of a valve.

Why take chances with so much at stake? The safe, positive, economical way to eliminate failures, such as the one illustrated above, is to make the running of a Baker Model "C" Roto-Vert Casing Scraper a part of your standard operating procedure.

BAKER OIL TOOLS, INC. • HOUSTON • LOS ANGELES • NEW YORK

ROTO-VERT
CASING SCRAPER
PRODUCT NO. 620-C

It takes all three

to get results—

1 THIS SETTING TOOL

saved the Oil Industry over 4 years of rig time ...*in one year*

The Baker Wire Line Setting Tool, the "power package" that supplies the controlled force necessary to set Baker Bridge Plugs, Retainer Production Packers and Cement Retainers on wire line, brought *dependable, time-saving* wire line bridge plug and packer service to the oil industry.

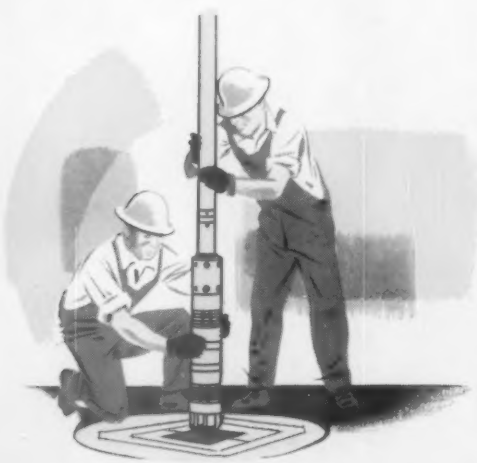
This tool brought together (a) the established performance of Baker Bridge Plugs and Packers with (b) the highly efficient wire line service organizations, thus providing operators with a dependable source that saved the oil industry an estimated four years of rig time *in one year.*

2 THESE WIRE LINE SERVICE COMPANIES

RUN A BAKER BRIDGE PLUG, RETAINER PRODUCTION PACKER, OR CEMENT RETAINER ON WIRE LINE, EVERY FORTY MINUTES DAY AND NIGHT, AROUND THE CLOCK... *AROUND THE WORLD.*

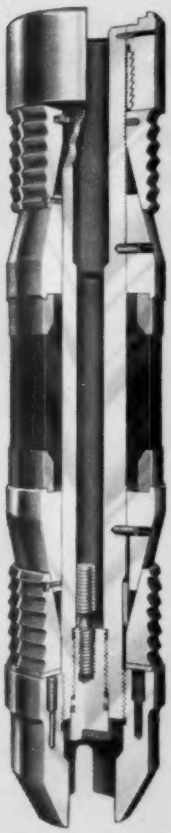
B-J Services, Inc.
Bird Well Surveys, Inc.
The Dia-Log Company
Dowell Incorporated
Flash Perforating Company
Ford Alexander Corporation
Huskey Guns, Inc.
Lane-Wells Company
McCullough Tool Company
Perforating Guns-Atlas Corporation
Petro-Tech Service Company
Ram-Guns, Inc.
Schlumberger Well Surveying Company
Schlumberger Surenco, S. A.
Schlumberger of Latin America, S. A.
Schlumberger Overseas, S. A.
Société de Prospection Électrique
Trinidad Oilfield Service Limited
United Oilwell Service, S. A.
Welex Jet Services, Inc.
The Western Company

The combined trained personnel of these companies comprises a service organization with over 1,000 men in the field. Nearly 400 service locations ensure maximum availability of Baker Wire Line Bridge Plugs, Packers and Cement Retainers.



3 THESE PRODUCTS

Provide the end result: Superior Performance, Dependability with Maximum Drillability.

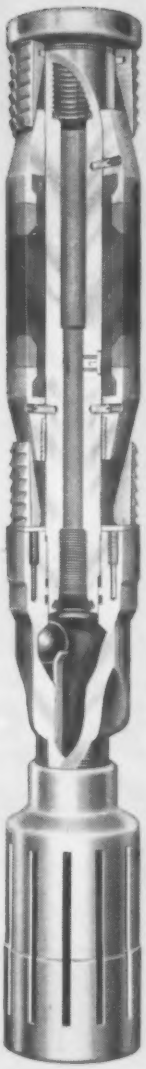


BAKER WIRE LINE BRIDGE PLUG
Product No. 400-N

Provides dependable, leak-proof, pack-off even under conditions of extreme pressure and temperature.

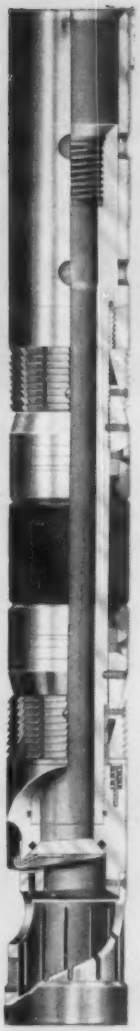
Drills up easily because in addition to being short, it has been especially designed to break up under the action of the bit.

Is immediately available everywhere, in either cast iron or magnesium.



BAKER WIRE LINE CEMENT RETAINER
Product No. 400

Provides the same reliable performance established over the years, plus many new advantages. Try it with the Stinger or Latching Subs for a variety of new applications.



BAKER WIRE LINE RETAINER PRODUCTION PACKER
Product No. 415-D

Provides unsurpassed performance under *any well condition* and a versatility that permits superior application for any production or packer requirement, including:

· SINGLE ZONE · DUAL ZONE · DUAL ZONE CROSS-OVER · PERMANENT WELL COMPLETIONS · PARALLEL STRING COMPLETIONS · OFF-SHORE INSTALLATIONS · GAS INJECTION · WATER INJECTION · TESTING

Over 85% of all Retainer Production Packers are now set on wire line.

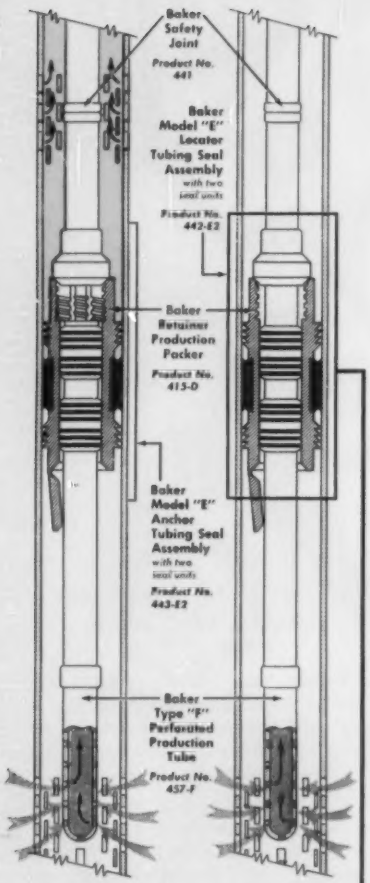
BAKER
OIL TOOLS, INC.

HOUSTON · LOS ANGELES · NEW YORK

SINGLE ZONE

DUAL ZONE
PRODUCTION

WITH **1** **BAKER**


Baker Safety Joint
Product No. 441
Baker Model "E" Locator Tubing Seal Assembly
with two seal units
Product No. 442-E2
Baker Retainer Production Packer
Product No. 415-D
Baker Model "E" Anchor Tubing Seal Assembly
with two seal units
Product No. 443-E2
Baker Type "F" Perforated Production Tube
Product No. 457-F

TYPICAL DUAL ZONE HOOKUP

TYPICAL SINGLE ZONE HOOKUP

Right: Picture shows actual detail of seal units

RETAINER
PRODUCTION PACKER

Do you know that with only ONE Baker Retainer Production Packer you can equip your well for *either* SINGLE ZONE or DUAL ZONE production? And that you can accomplish *any* type of completion for *any* method of production to meet *fixed* or *changing* well conditions?

A single Baker Retainer Production Packer will also outperform many specialized tools when used as a TESTING PACKER • SQUEEZE PACKER • GAS LIFT PACKER • PERMANENT COMPLETION PACKER • WATER FLOOD PACKER • GAS INJECTION PACKER • CORROSION CONTROL PACKER • TUBING ANCHOR • ONE-WAY BRIDGE PLUG • PERMANENT BRIDGE PLUG.

Every production man should be familiar with the many operating advantages of this "Universal Type" Packer, which include . . .

WIRE LINE SETTING • SETTING UNDER HIGH PRESSURE • NO EXCESSIVE "SET-DOWN" WEIGHT OR TENSION • HOLDS PRESSURE FROM ABOVE OR BELOW • PACKS-OFF AND HOLDS UNDER HIGH BHT • RESISTS CORROSION • EASILY DRILLABLE.

Ask any Baker representative or office for complete details. There is no charge and no obligation for specific recommendations and completion planning advice available from Baker Technical Advisers. Why not be prepared for your next completion?

BAKER OIL TOOLS, INC.
HOUSTON • LOS ANGELES • NEW YORK

BAKER
RETAINER PRODUCTION PACKER

If your well is worth completing . . . it's worth completing well

EQUIPMENT BULLETIN NO. 317

BAKER

IS

Still First

First to use cement in Guiding, Floating, and Cementing Equipment in 1927, BAKER always has pioneered and field-proved the most advanced tools and methods for successful "First-time" cementing.

First in **RESULTS...**

First in **QUALITY...**

BAKER *will continue to be* **FIRST** *in the future*

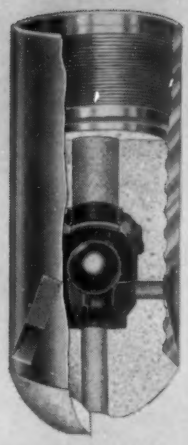
BAKER Superiority in Cementing Equipment starts with the use of heavy walled steel tubular stock for all Shoes and Collars, with threads accurately cut to meet API or special thread specifications, for any size casing.

BAKER Cement Float Shoes and Guide Shoes, which have a rounded nose made of strong concrete, guide the casing safely to the cementing point, past any possible hole irregularities.

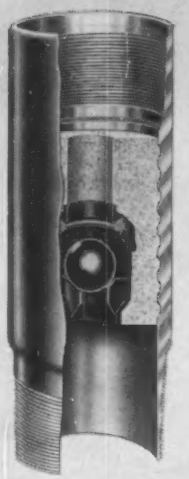
BAKER Formula Concrete is strong enough to withstand any floating or cementing pressures safe for the casing—but it drills up quickly and safely into small, harmless fragments that are easily circulated out of the well.

BAKER Back-Pressure Valves always have been First Choice of experienced operators. The dependable "floating ball" made of hard, abrasion-resistant Bakelite, seats and seals against a tough, resilient synthetic rubber ring which is anchored in the plastic valve cage. The ball presents a different sealing surface to the rubber seat each time it seats; and there are no springs or other non-drillable materials to prevent quick, safe drilling out.

BAKER "Whirling" Action—provided by baffled ports in either Shoes or Collars—ensures the most even distribution of cement slurry ever possible. "Whirling" washes and conditions the hole, without breaking down the formation, and the cement slurry is uniformly distributed to minimize the hazard of channeling.



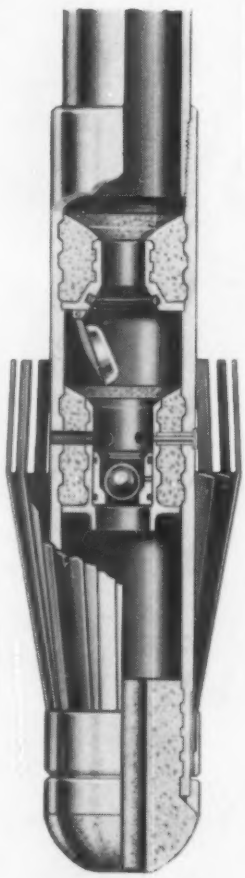
Baker Cement Wash-Down Whirler Float Shoe
Product No. 120



Baker Cement Float Collar
Product No. 101 M & F

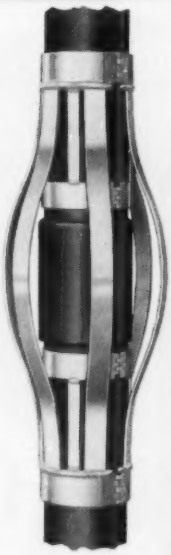
Baker Cement Guide Shoe
Product No. 102

BAKER also offers many successful devices for unusual cementing requirements, example: BAKER Triplex Equipment which makes it possible to cement *above* a low-pressure, highly permeable zone. When the cementing point is reached, a Tripping Ball is dropped and seated. Pressure is then supplied to open the cementing ports and to permit a Metal Petal Basket to expand. The Basket expands up to twice the diameter of the casing string, and forms a bridge, even in oversize, irregular size or directionally drilled holes. Cementing in the conventional manner then directs the slurry upward and all cement is held safely *above* the Basket. The swivel-mounted Basket permits rotation of the casing.



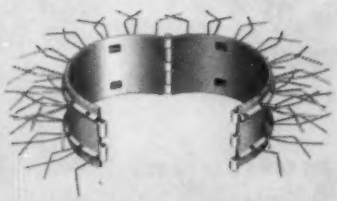
Baker Triplex Cementing Shoe
Product No. 1363

For BETTER *"First-Time Cementing in* YOUR *wells . . . call* **BAKER**



Baker Model "H" Hinge-Lok
Casing Centralizer
Product No. 9113

Baker Model "G"
Casing Centralizer
Product No. 910-G



Baker Model "C" Hinge-Lok
Wall Scratcher
Product No. 900-C

Baker Model "C" Solid-Ring
Wall Scratcher
Product No. 901-C

BAKER WALL SCRATCHERS remove mud cake effectively, but *only from the area to be cemented.* As the casing is being run in the hole, the wires on Baker Wall Scratchers remain close against the casing and do not damage the vital filter cake built up on sections through which the scratchers pass. Even lifting the casing out of the slips does not activate the scratcher wires because the Scratcher is mounted between Stop Rings three feet apart, and remains stationary until the actual "wall scratching" operation is started over the area to be cemented. Then, however, the double row of scratcher wires, mounted in a double shell and overlapped for added strength, *really go to work.* The strong, overlapping wires cover the entire 360-degree surface of the well bore; the mud sheath is rapidly scratched away; and the original formation is exposed for far better bonding of the cement.

Two models are available . . . The HINGE-LOK (Product No. 900-C) for operators who prefer to *close the scratcher around* the casing and lock it in closed position . . . and the SOLID RING (Product No. 901-C) which is *slipped over* the casing. Each model can be furnished with 4½-inch long scratcher wires for normal clearance programs; or with 2½-inch long wires for "slim hole" clearances.

The Baker representative in your area is ready with helpful suggestions for securing a good "first-time" cement job with Baker Wall Scratchers. Why not take advantage of this service?

THE BAKER WAY TO *Better Cementing*

For Better Bonded, All Around Primary Cementing, operators everywhere rely upon **BAKER CASING CENTRALIZERS** *and* **BAKER WALL SCRATCHERS,** *and here's why . . .*

Centering the casing throughout the cementing area greatly increases your chances for securing a successful initial cement job. And BAKER CASING CENTRALIZERS are your best bet to be sure that ample annular space for the cement is present around the casing, *throughout the area to be cemented.* This is true because Baker Centralizers have that *balanced combination* of proper spring length and proper "reach" (bowed height) of the springs. Then, to make certain that Baker Casing Centralizers bring you the required Maximum Centering Force *at the cementing point,* all springs are pre-set and pre-tested in hydraulic presses which completely flatten each spring, and then permit it to return to the desired bowed height. This flattening also tests each spring for cracks or flaws—another step to provide you with *effective centering force* at the cementing point.

BAKER CASING CENTRALIZERS are available in either the HINGE-LOK Type (Model "H") which is hinged for easy mounting, or the Model "G" Solid Type Centralizer which is merely *slipped over* the casing.

Various "Ranges" of Baker Casing Centralizers cover all bore requirements from "slim holes" with close tolerances, to large-diameter, oversize, irregular holes, or even where cavities are anticipated.

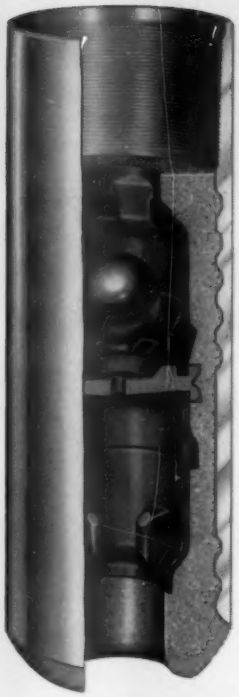
Any Baker representative is ready to help you get "first-time" cementing results with Baker Casing Centralizers.

For CONTROLLED *Scratching and* EFFECTIVE *Casing Centering . . .call* **BAKER**

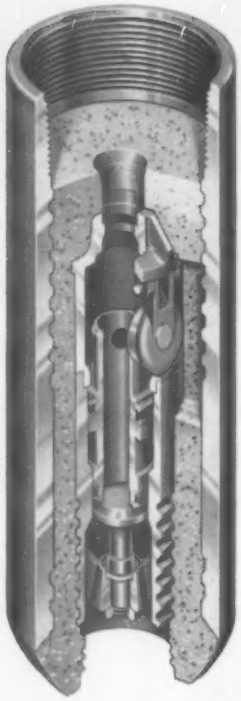
BAKER

OFFERS

Another First



Baker
Flexiflow
Fill-Up Shoe
Product
No. 160



Baker
Differential
Fill-Up Shoe
Product
No. 1081

Now you can fill your casing automatically... from the bottom while it is being run

Save the *time* and the *mess* of surface filling the casing—Eliminate *destructive pressure surges* which can cause cementing failures. Baker DIFFERENTIAL FILL-UP Equipment, and Baker FLEXIFLOW FILL-UP Equipment permit the casing to fill automatically from the bottom while it is being run. In addition, the destructive "high-pressure surges" created when casing is run equipped with conventional floating equipment, are *practically eliminated* by the use of this successful new equipment.

Baker DIFFERENTIAL FILL-UP Equipment (which is recommended for wells of any depth) contains a differential valve which opens and closes as the pressure varies, so that the casing is filled to within approximately 90% of the fluid level of the annulus (using *either* a shoe *or* a collar) or to within approximately 81% of the fluid level of the annulus using *both* a shoe *and* a collar.

Baker FLEXIFLOW FILL-UP Equipment (which is recommended for wells of moderate depth) contains a variable valve consisting of a self-adjusting flow control diaphragm with a small hole through its center, that automatically opens wider or closes to provide *minimum bottom-hole pressure increases* and regulated fill of the casing.

Both types of equipment contain a back-pressure valve to be used at the discretion of the operator for "floating" or for cementing.

Ask any Baker representative for illustrated booklets explaining this new, safe, time-saving, trouble-saving equipment which *prevents* destructive "high-pressure surges."

BAKER OIL TOOLS, INC.

HOUSTON - LOS ANGELES - NEW YORK

Printed in U.S.A. 20M 8-55

To eliminate "Filling" at the Surface, and "Pressure Surges" at the Bottom . . . call **BAKER**

ESSENTIAL DATA

describing development and use of

Strata-Crete 6*

® TRADE MARK

the improved perlite aggregate

for better oil well cementing

STRATA-CRETE 6 is an improved oilwell cement perlite aggregate produced by Great Lakes Carbon Corporation and marketed by Great Lakes Corporation, a wholly owned subsidiary. The development of STRATA-CRETE 6 has made possible the obtaining of lightweight cement slurries with bridging properties at a slurry volume cost comparable to other commonly used cement mixes.

* Refers to gallons of water required for each cubic foot of Strata-Crete 6.

question	answer
Does Strata-Crete 6 contain any material other than perlite?	No, it contains only expanded and unexpanded perlite.
Is the bulk density of Strata-Crete 6 more than regular Strata-Crete?	Yes, the bulk density of Strata-Crete 6 is approximately 43#/cu. ft. The bulk density of regular Strata-Crete is approximately 13#/cu. ft.
Does a cubic foot of Strata-Crete 6 contain as much expanded perlite as regular Strata-Crete?	Yes, it contains a cubic foot of expanded perlite identical to regular Strata-Crete.
How was it possible to increase the weight of this cubic foot of expanded perlite?	Within a cubic foot of 13#/cu. ft. expanded perlite there is a certain amount of unoccupied space between the expanded particles. These vacant spaces have been filled with unexpanded perlite ore fines. By doing this, the weight per cubic foot has been increased but not the bulk volume.
Where are the unexpanded perlite ore fines obtained and prepared for us in producing Strata-Crete 6?	They are obtained from the Socorro, New Mexico, deposit of Great Lakes Carbon Corporation and are selectively air classified in its plant. At the present time, all Strata-Crete 6 is produced at this location.
Will the slurry weights at 3000 P.S.I. using Strata-Crete 6 be more or less than obtained with regular Strata-Crete?	They are approximately the same as the slurry weights at 3000 P.S.I. obtained with regular Strata-Crete.
Why does Strata-Crete 6 have better bridging properties than regular Strata-Crete?	The addition of unexpanded classified fines does not necessarily extend the particle size range present in regular Strata-Crete but this addition does bring about a better gradation of particle sizes within this range.
How was it determined that Strata-Crete 6 requires six gallons of water per cubic foot?	It was proven by laboratory testing and years of field usage that a cubic foot of 13# expanded perlite such as Strata-Crete required 4 gallons of water. Consequently, it was only necessary to determine the additional amount of water required for the unexpanded perlite fines. Our laboratory reported that the ore fines required 2 gallons water. Hence, six gallons of water is required per cubic foot Strata-Crete 6.
Why is the slurry volume at 3000 P.S.I. of Strata-Crete 6 less than the atmospheric slurry volume?	Because approximately 1.6 gallons of water is forced by pressure into the internal voids of the expanded perlite portion of a cubic foot of Strata-Crete 6.
How much pressure is required to fill the internal voids of the expanded perlite?	It has been found that the internal voids are filled for all practical purposes when pressures of 1200 to 1500 P.S.I. have been attained.
Does the addition of Strata-Crete 6 lower the early compressive strengths of neat cement?	Yes, almost any cement additive that requires additional water will lower the early strength of neat cement. However, Strata-Crete 6-Cement mixes that we recommend have more than enough early strength to prevent casing movement.

Will the use of Strata-Crete 6 with cement aid in obtaining maximum penetration from perforating operations with less shattering and fractures occurring?

Almost any additive that lowers the early compressive strength of neat cement will aid in this respect. We think, however, that lower early strength plus the use of an aggregate will result in even less shattering and fewer fractures. Strata-Crete 6-cements are very resilient.

Does the use of Strata-Crete 6 affect the thickening time of neat cement?

We know from field usage of expanded perlite (Strata-Crete) that it does not seem to accelerate the thickening time. We have tested the effect of the unexpanded perlite fines and we can conservatively state that their use will not accelerate thickening times of neat Portland cements. Test results actually indicated an extension of thickening time.

Will the addition of Strata-Crete 6 to cement result in making the cement sulfate resistant?

We do not presently have sufficient data to answer this question. It can be stated, however, that perlite is highly resistant to attack by sulfates.

How impermeable are Strata-Crete 6-Cements?

The mix ratios that we recommend after 7 days curing measured no water permeability which indicates less than 0.01 millidarcies.

Why can Strata-Crete 6 be used as economically as Portland cement?

A cu. ft. (43#) of Strata-Crete 6 with its required water at 3000 P.S.I. has a slurry volume of 1.10 cu. ft. equivalent to one sack (94#) of most Portland cements. The average cost of Strata-Crete 6 per cu. ft. from your oilwell cementing service company is approximately the same as Portland cements.

Why can Strata-Crete 6-Cement mixes be used as economically as other mixes now being commonly used?

The addition of bentonite to a Strata-Crete 6-Portland cement mixture would contribute to the slurry volume in a proportional amount. The use of a Strata-Crete 6-Cement mix to fill a given annulus also results usually in less ton-mileage expense from the bulk station to the well.

Why do you consider Strata-Crete 6 to be an exceptional product?

To our knowledge, it is the most economical product presently available in commercial quantities that will both lighten the cement slurry and also impart worthwhile bridging properties.

Do you think that the reducing of the slurry weight contributes more to obtaining desired fillup than the bridging properties?

From experience on many wells we know that the bridging properties of expanded perlite has made it possible to obtain column fillups to desired heights that had not previously been reached with lightweight cement slurries alone. We think the two properties combined are more effective than either of them alone.

Do you think Strata-Crete 6 can be advantageously used on most casing jobs?

Regular Strata-Crete has been used for years by most operators to overcome serious cementing problems. The general use of Strata-Crete on average casing jobs was handicapped by its low slurry volume of .63 cu. ft. @ 3000 P.S.I. resulting in higher slurry volume cost/cu. ft. than other commonly used cement mixtures.

Strata-Crete 6 offers all of the proven efficiency of regular Strata-Crete at a more economical slurry volume cost. The theoretical slurry volume cost of most Strata-Crete 6-Cements is no greater than that of most other commonly used mixes.

For your same present fillup cost using other cement mixes you can, by using Strata-Crete 6, probably obtain 0.5 lb./gal. less slurry weight and impart bridging properties to the mixture. This reduction in slurry weight plus bridging properties should result in less loss of slurry than experienced with other cement mixes on average wells. Consequently, we believe you will find that the equivalent theoretical cost of Strata-Crete 6-Cement to other mixes in actual practice will result in a more economical cementing cost.

Your comments or requests for further clarification and data concerning the use of Strata-Crete 6 will be welcomed. Samples for laboratory testing will be forwarded upon request or can be obtained at most oilwell cementing bulk station points.

Use Strata-Crete 6 on your next job and we believe you will agree that the remarkable fillup properties of this product at low cost will warrant its use on most of your future wells.

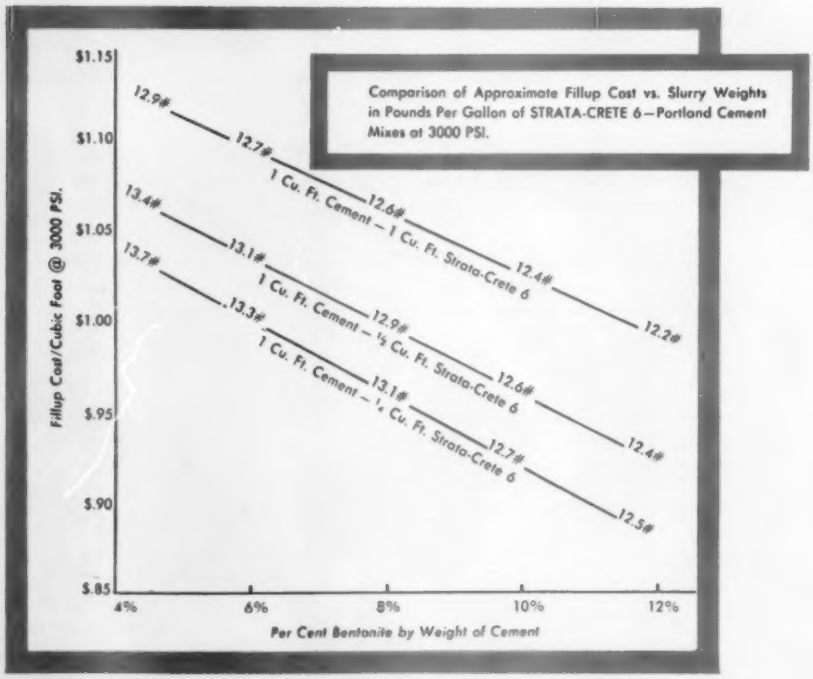
Compressive Strength *(Approx.) of Recommended Strata-Crete 6-Cement Mixes*

Portland Cement — Type I.
Pressure — 1500 P.S.I.
Temperature — 140°F.

Cu. Ft. Strata-Crete 6 per Sack Cement	% Bentonite By Wgt. Cement	Gallons Water Per Sack Cement	Compressive Strength, P.S.I. 24 Hrs.	48 Hrs.	72 Hrs.
1	2	12.5	750	960	*1240
1	4	13.7	575	800	* 950
1	6	14.8	500	690	* 825
½	4	10.7	900	1125	*1325
½	6	11.8	775	960	*1100
½	8	12.7	615	775	* 900
½	10	14.1	500	640	* 735
⅓	4	9.7	1100	1415	*1580
⅓	6	10.8	920	1130	*1260
⅓	8	11.7	710	860	* 965
⅓	10	13.1	550	695	* 790

*No water permeability detected on specimens which indicates that the permeability is less than 0.01 millidarcies.

Note It may be of interest to know that in breaking the specimens it was observed that they were resilient and did not necessarily shatter on failing.
Most of the data herein displayed was obtained from laboratory tests conducted by Drs. Harvey T. Kennedy and Paul Crawford, Consultants, College Station, Texas.



Strata-Crete 6, a new perlite aggregate, retains all advantages of its predecessor, Strata-Crete, and has added other desirable properties that warrant its economical use, according to the manufacturer.

Strata-Crete 6 provides oil well cement slurries with low density, excellent bridging properties, and adequate strength. Field usages have already demonstrated for these slurries an extraordinary high and efficient fillup factor at normal pump pressures.

The light weight and relatively low hydrostatic head allow placement of Strata-Crete 6 slurries with a minimum of pressure against the formation. The combination of light weight and improved bridging properties has proved useful in preventing cement migration and pressure parting of the formations.

Strata-Crete 6 cements perforate cleanly with maximum penetration, allowing exact perforating in critical zones, it is asserted. Scouring properties minimize channeling and allow placement in the annulus with little contamination from mud and formation fluids. The early compressive strengths of most Strata-Crete 6 cements are high enough to prevent casing movement and low enough to allow maximum penetration from perforating.

Independent laboratory testing of Strata-Crete 6 cement samples proved that they had very low permeability.

Strata-Crete 6 is a product of the Great Lakes Corporation, which is a wholly-owned subsidiary of Great Lakes Carbon Corporation.

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A Subsidiary of Great Lakes Carbon Corporation
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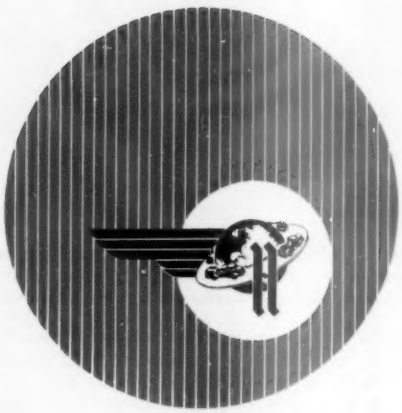


HALLIBURTON REPORTS ON...

5 IMPORTANT PRODUCTION IMPROVEMENT TECHNIQUES

- **Formation Fracturing**
- **Oil Well Cements**
- **Isoflow Logging**
- **Drill Stem Testing**
- **H V Acid**

Specialists in Petroleum Engineering, Chemistry, Metallurgy and Electronics work together as a team at Halliburton to provide a number of *integrated services* for the oil producing industry. This is a report on five of these services and the progress that has been made through research and development . . . to perfect them in the laboratory and prove them in the field.

In developing these five production improvement techniques to their present importance, Halliburton utilized the "know-how" of 2 million job experience . . . the "know how" of 30 years' intensive research. If your job in the petroleum industry has anything to do —- directly or indirectly — with increasing the production of oil, the information in the following pages merits your attention.

HALLIBURTON OIL WELL CEMENTING COMPANY

PROGRESS IN SERVICE THROUGH RESEARCH

PROGRESS IN FORMATION FRACTURING . . .

PROVED PRODUCTION STIMULANT

Reservoir engineers estimate that this process has increased reserves by at least 2-billion barrels; perhaps up to 4-billion barrels.

Hydraulic Fracturing was first offered commercially to the oil industry by Halliburton in March, 1949. Since then, procedures have been developed to fit all types of well conditions, and are accepted as proved production stimulants for both old and new wells.

Research and development efforts applied to fracturing methods and their attendant chemicals have as one of the goals to provide an ideal fracturing fluid with the following characteristics:

1. No free water to harm the producing formation.
2. Low fluid friction while being pumped.
3. High gel strength.
4. Low fluid loss.
5. Good viscosity index.
6. Stability to agitation.
7. Compatibility with the native crude oil.
8. Minimum closed-in time after treatment.
9. Resistant to emulsification.
10. Economy.

FLUID CHARACTERISTICS AND VISCOSITY

Fluids are normally classed in two distinct groups:

1. Newtonian (or true fluids)
2. Non-Newtonian fluids

The Newtonian fluid is a molecularly dispersed liquid, or one in which the rate of shear is proportional to the shearing stress. Therefore, regardless of the flow rate, the viscosity does not change when held at a constant temperature.

Non-Newtonian fluids are further subdivided according to their flow characteristics: Plastic flow, pseudo-plastic flow, and delitant flow. The type normally exhibited by certain fracturing fluids is pseudo-plastic. With this type flow, the rate of shear increases faster than linearly with shearing stress and is, therefore, not a straight-line function.

Emulsions and gel type fracturing fluids follow this flow pattern. Viscosity measurements with these fluids are invalid and have no correlation with true viscosity units. They are relative when measured with the same instrument under the same shear conditions.

To determine the true characteristics of these types of fluids, it is necessary to determine the slope of the shear-stress curve of the material. With this information, relative flow characteristics and apparent viscosities under specified flow conditions can be obtained.

With fracturing fluids of this nature, a viscosity value can be very misleading. For example, a fluid measuring 4,000 centipoise viscosity with a particular instrument may show extremely low viscosity under fast pumping conditions. Therefore, it follows that these fluids cannot follow the Reynolds number — friction factor curve because of the variable apparent viscosity with change in flow rate.

Viscosity data given in the chart herein show the wide range of apparent viscosities encountered with a prepared fluid under various shear conditions. These are average values obtained with a particular instrument and cannot be used satisfactorily for calculating flow characteristics or friction factors for the fluids.

FLUID LOSS PROPERTIES

A fluid with low fluid loss property has greater efficiency, producing more fracture area per unit volume of fluid than one with a high leak-off rate. This makes it possible to place more propping agent in a fracture without a screen-out.

With additives currently available, it is possible to incorporate this property into many fracturing fluids. Adomite, distributed by Halliburton, can be utilized in oils or Vis-O-Frac to lower fluid loss to the range of 5 to 15 cc., as determined by API Code 29.

This code is the standard method of determining fluid loss. The data obtained is not always valid for calculating fluid efficiency under well conditions but is only a *relative* means of comparing the possible fluid loss.

PROPPING AGENTS

Spherical particles are more effective as propping agents than those of irregular form. Spheres provide greater packed permeability, have greater structural strength, and can be placed within a fracture more efficiently.

Rounded grain silica sands are used for hydraulic fracturing operations. They are carefully graded to prevent wide variation in grain size distribution. The Ottawa type 20-40 U.S. mesh sand is considered the standard grade, although finer and coarser materials are sometimes used.

PROGRESS IN PROPORTIONING

Many improvements in fracturing have been created by continuously proportioning sand into fracturing fluids. Adding and mixing sand immediately before the fracturing fluid is pumped into the well allows greater flexibility in all fracturing operations.

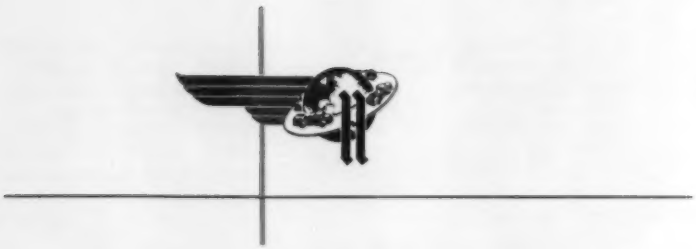
Concentrations of sand may be tapered for a greater margin of safety when fracturing unknown or hard-to-fracture formations. Sand concentrations may be increased with the positive indication of higher injection rates, allowing more economical placement of sand with smaller amounts of fracturing fluid. Screen-outs may be minimized by lowering sand concentration when rising injection pressures indicate possible trouble.

Units of 25 BPM, 40 BPM and 70 BPM, covering a wide range of sand concentrations, are available to "tailor-make" your fracturing job.

PROPERTIES OF HALLIBURTON FRACTURING FLUIDS

HYDRAFRAC	SANDOIL	EMULSIFRAC	VIS-O-FRAC	ACIDFRAC	WATERFRAC
COMPONENTS					
Oil soluble soap. Internal chemical breaker.	No special additive	Emulsifier Chemical breaker Fluid loss control additive 5% fresh water 94% oil	Mono basic soap Gelling agent	Emulsifier Usually 88% acid 12% oil	Gelling agent Chemical breaker
BASE FLUID					
Kerosene or diesel Some light crude oils	Specially prepared refined oils or crude oils	Crude oil or light refined oils	Crude oil or light refined oils	Hydrochloric acid of 5 to 15% strength	Fresh or salt water
METHOD OF FIELD MIXING(1)					
Batch	Continuous	Batch or continuous	Batch or continuous	Batch	Batch
TYPE OF FINISHED FLUID					
Pseudo-plastic gel No emulsion	True fluid	Pseudo-plastic Emulsion-water outer phase	Pseudo-plastic gel No emulsion	Pseudo-plastic Emulsion-oil outer phase	Pseudo-plastic gel No emulsion
METHOD OF VISCOSITY REDUCTION OF FLUID					
Internal chemical breaker destroys gelling agent.	Temperature and dilution by formation oil	Internal chemical breaker destroys emulsifier — oil & water of low interfacial tension separate — no reemulsification	Easily diluted by formation oil — to low viscosity	Reaction with calcareous material or with time and temperature	Internal chemical breaker, also dilution
FLUID AND VISCOSITY CHARACTERISTICS					
Non-Newtonian fluid 5000-9000 cps. max. (2)	Newtonian fluid 50-150 cps. at BHT preferable. Maximum 800 cps. at surface temperature for best handling	Non-Newtonian fluid (3) 8400 cps #3 @ 6 RPM 3900 cps #3 @ 12 RPM 1040 cps #3 @ 30 RPM 640 cps #3 @ 60 RPM	Non-Newtonian fluid (3) 5000 cps #3 @ 6 RPM 2800 cps #3 @ 12 RPM 1250 cps #3 @ 30 RPM 850 cps #3 @ 60 RPM	Non-Newtonian fluid (3) 6500 cps #3 @ 6 RPM 3800 cps #3 @ 12 RPM 1750 cps #3 @ 30 RPM 1150 cps #3 @ 60 RPM	Non-Newtonian fluid (3) 1760 cps #3 @ 6 RPM 1450 cps #3 @ 12 RPM 1070 cps #3 @ 30 RPM 800 cps #3 @ 60 RPM
FLUID LOSS PROPERTIES — API CODE 29					
No fluid loss until gel is broken	Varies with oil used but preferably low. Can be lowered with low fluid loss additives such as Adomite	Will vary with oil used but normally very high. Can be lowered to approx. 10-15 cc with CEF low fluid loss additive	Will vary with base fluid but normally will be 10-45 cc. Can be lowered with Adomite to 5-15 cc.	Dependent on emulsifier which is controlled by well conditions	Will vary with strength of gel. Normally 10-20 cc.
TEMPERATURE STABILITY OF FLUID					
Breaks with increase in temperature. Rate dependent on internal breaker concentration	Normal viscosity-temp. relation. Paraffin oils have drastic viscosity reduction with increase in temp.	Stable at high temp. (225° F). Break time vs. temp. controlled by breaker concentration	Slight decrease in viscosity with increase in temp. Viscosity index much higher than the base oil	Sufficiently stable for safe placement in wells above 200° F.	Slight decrease in viscosity with increase in temp.
SAND TRANSPORTING CHARACTERISTICS					
Excellent. Has transported over 6 lbs. per gallon	Will vary with viscosity of oil and pump rate. Normally 1 to 3 lbs. per gallon	Excellent — sand will not fall even under static conditions. Will support indefinitely in excess of 10 lbs. per gallon	Good — falling rate very slow — 5½ lbs. per gallon has been used in field. Normally 1-3 lbs. per gallon is used	Excellent — sand will not fall under static conditions. Will support 10 lbs. per gallon until gel begins to break.	Good — falling rate very slow. Under normal treating conditions can transport 3 to 5 lbs. per gallon.
TYPES OF FORMATIONS BEST SUITED					
All oil and gas bearing formations.	All oil bearing formations. Lighter fracturing oils should be used in gas zones because of lack of diluent	All oil and gas bearing formations	All oil and gas bearing formations	All oil and gas bearing formations having some acid solubility (5-100%)	All water bearing zones both fresh or salt water. Injection, disposal or production wells.

(1) Depends on equipment available in specific areas.
(2) Viscosity measured with HOWCO consistometer.
(3) Brookfield viscometer readings with spindle and speed as noted.



MULTIFRAC

A process used to create a series of fractures in long sand sections which are impossible to isolate by conventional methods. Soluble plugging agents are often spotted to temporarily seal off existing fractures so that the fracturing medium may be diverted to create new fractures.

VERTIFRAC

Vertical fractures are especially desirable in sands laminated with shale, or sands of varying permeability in open hole completions. Although there has been considerable discussion relative to the type fracture made with conventional fracturing fluids, laboratory and field data indicate that if the face of the formation has been sealed and pressures confined to the well bore, the thick wall principle will apply, usually resulting in a vertical fracture being initiated.

With Vertifrac, the well is slowly sealed with a low fluid-loss fluid containing granular lost circulation materials. Pressure is then increased abruptly to obtain a formation breakdown. The usual result is a vertical fracture. This is followed by conventional fracturing fluids to extend the fracture.

Care must be exercised in selecting wells for applying this technique to prevent fracturing vertically into water or gas which may be nearby.

FRACPAC

Many techniques have been used with varying success to control the movement of unconsolidated sands into a well bore. Recently it has become possible to effectively control such movement with a comparatively inexpensive procedure where graded sands are hydraulically placed against the formation with fracturing fluids compatible with the particular formation and well condition. Generally, a slotted or pre-perforated liner is then washed into place.

Production increase as well as control of sand movement has been obtained on many of these treatments. This treatment gives a larger area along the interface of the injected sand and the formation sand which should reduce the velocity of the production fluid along this interface — possibly below the critical velocity for movement of the formation sand, resulting in less tendency of its plugging the pack. (Either a predetermined amount of graded sand is used, or it is pumped into the formation until a predetermined pressure-buildup has been reached. The surplus is reversed out and the liner washed in place). The formation should be adequately cleaned prior to these treatments; otherwise an impermeable barrier could exist in the interface between these two sands.

BIGFRAC

These are down-the-casing, high injection rate, hydraulic fracturing treatments utilizing pumping equipment accumulating several thousand horsepower. High capacity sand proportioners, booster pumps, tanks, and wellhead connections have been developed to facilitate injection rates of as much as 65 bbls/min.

Most treatments have employed viscous oils. However, the use of Vis-O-Frac has become popular because of the low friction loss encountered.

RECENT DEVELOPMENTS IN

OIL WELL CEMENTS

Cements used in oil wells must possess three primary properties:

1. Proper water-cement ratio
2. Sufficient fluid time to allow placement
3. Develop enough strength in a minimum time to bond pipe to formation

The water ratio is important since cementing material must contain sufficient water to make it pumpable, yet not cause separation upon setting. The two terms used for water ratios are: maximum and minimum. Maximum water is that amount which can be mixed with a cement to produce a set volume equal to the slurry volume. Minimum water is the smallest volume which can produce a pumpable slurry.

THICKENING TIME

A cementing slurry should have sufficient pumping time to allow placement at any given depth. Temperature and pressure are the primary factors which affect the fluid time of cement. The higher the temperature, the faster a cementing material will set, while pressure will accelerate the cement slurry only up to approximately 5,000 psi.

COMPRESSIVE STRENGTH

Once in a well, the slurry should set in a minimum time and develop adequate strength to bond the casing to the formation. Numerous types of cementing compositions are in use. Some are designed for general usage, while others have application only for special jobs.

POZMIX CEMENT

A blend of portland cement and pozzolanic material which has properties not offered by other types of cementing compositions. The addition of pozzolans to portland cement reduces thixotropic action and allows longer movement of the cement should it be necessary to shut down while mixing or displacing. Pozzolans have lower densities than portland, and, as a result, offer reduction in slurry weight without the use of large volumes of mixing water.

The lower early strengths enable perforating with greater penetration and less shattering. Waiting on cement time for Pozmix cements is consistent with normal practice for other cements or admixtures under the same conditions.

EXPANDED PERLITE

Used with cement, produces a light weight slurry with bridging characteristics. Slurries composed of cement, small amounts of bentonite and expanded perlites such as Strata-Crete 6, are particularly useful in zones subject to loss of circulation during cementing.

DIACEL

A very low density admix material for primary cementing jobs which offers a high fill-up volume based on a sack of cement and, with the addition of a low water loss additive, can have fluid loss values comparable to those found in drilling muds.

Diacel produces slurries as low as eleven pounds per gallon. The low fluid loss additive is applicable with other types of cementing compositions and reduces excessive water contamination to the oil bearing formations.

DIESEL OIL CEMENT (DOC)

An improved squeeze cementing material composed of portland cement, diesel oil and a surface active agent. It is very effective for sealing off unwanted water. The surfactant used allows twice as much cement to be added to a given amount of oil, which sets to form a dense material having a high compressive strength.

Unlike water slurries, DOC has an unlimited pumping time until contacted by water, and excess slurry can be reversed with minimum danger of cementing the tubing.

TOOL FOR INCREASED PRODUCTION . . .

ISOFLOW LOGGING . . .

A new, very accurate method of obtaining an injectivity profile on injection wells in secondary recovery projects is "Isoflow Logging."

This injectivity profile is obtained, regardless of injection rate, pressure or hole size, by the use of a radioactive tracer method. This tracer has a short half-life, allowing re-surveying of any well in a matter of weeks.

In Isoflow Logging, tubing is run to a level below the horizon to be surveyed. A control valve is placed in the injection flow line to divide the total injection water in any proportion between tubing and annulus.

A soluble radioactive material is then injected into either stream. This provides one stream containing a radioactive isotope and another stream free of radioactivity. An interface is thus established in the annulus above which the water routed through the casing enters the formation and *below* which the water routed through the tubing enters the formation.

This interface is located with a gamma ray counter, which operates in the tubing. By varying the percent of total injection water entering the tubing and annulus, the position of the interface may be changed at will. The amount of change — vertically in feet — is directly related to the change of input in barrels.

Thus a precise foot by foot profile is obtained, independent of hole size and injection rates, telling where every barrel of fluid goes.

HALLIBURTON EQUIPMENT RENDERS MORE EFFICIENT SERVICE

Halliburton has a special injectivity truck to perform this service. More than a year's field experience was used to develop the small, compact truck carrying recording instruments, logging tools, pumps and connections for logging the movement of the interface.

THE GAMMA LOG

It is standard practice to obtain a natural gamma log prior to the injection of the radioactive isotope to correlate between the original electric log and to provide a background in the event the water is going behind the casing shoe.

Practical examples of injection wells in which the injectivity profile has been greatly improved by remedial work are shown in Figures 1 and 2.

In Figure 1, the natural gamma log is on the left. The initial injectivity profile is the dotted line and indicates all the water entering the interval 1831′-1850′. The upper part of the formation is receiving no benefits from the flood. A selective plugging job was performed on the lower zone, followed by a selective acid job on the upper part of the formation. Another injectivity profile was run and a uniform distribution over the entire section from 1806′-1856′ was shown. In Figure 2, an initial injection survey indicated by the dotted line shows 85% of the entire injection water of 106 barrels per day entering the formation from 1868′-1876′. The well was shot with 20 quarts of nitroglycerin from 1870′-1881′ and from 1885′-1898′ with 25 quarts.

Another injection survey was then run, indicating uniform distribution from 1877′-1898′. The injection rate was increased to 1,010 barrels per day.

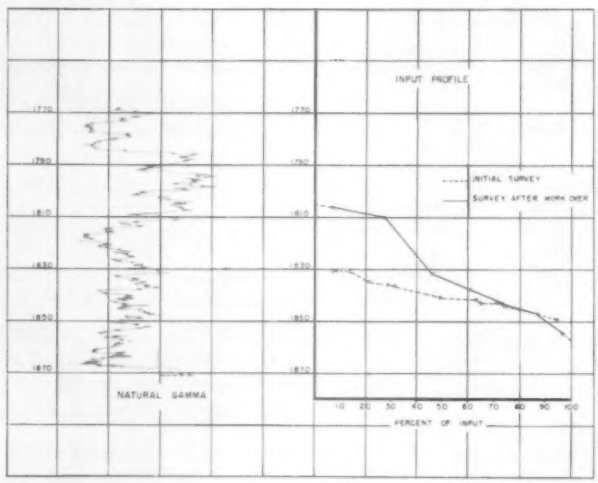


FIGURE 1

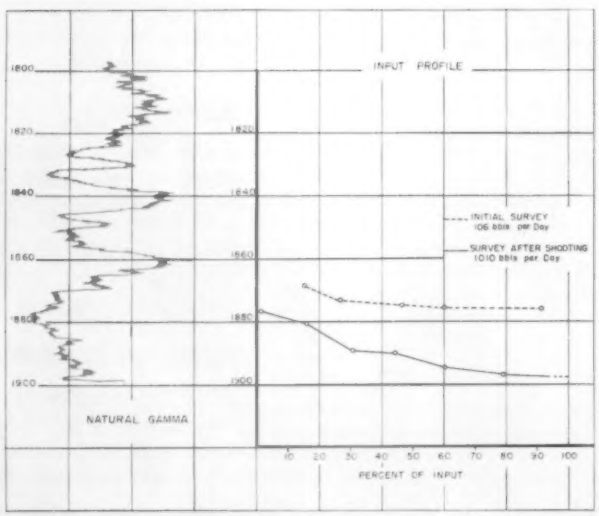


FIGURE 2

Latest Techniques in
DRILL STEM TESTING

Halliburton has developed several new techniques to further the science of Drill Stem Testing. One of the most significant is the use of the B. T. (Bourdon Tube) Pressure Recorder (Figure 1).

THE B. T. (BOURDON TUBE) PRESSURE RECORDER

This instrument, with its sensitivity and extreme accuracy is relied upon to supply the recorded pressure history during Drill Stem Testing. The accuracy of the B. T. Recorder is maintained by the use of specifically designed mobile service units.

One of the new techniques is "Double Closed-In Pressure." This means that when the testing tool is opened into an air chamber of a predetermined volume, this expansion chamber permits the release of the hydrostatic mud pressure; then by a limited amount of formation production, an Initial Closed-In pressure build-up curve is recorded.

The build-up curve can be mathematically extrapolated completion when required. This is considered the best manner to obtain virgin formation pressure.

Upon completion of the "Initial Closed-In Pressure" period, the well is opened to produce as on a normal Drill Stem Test.

When the flow period is completed, a "Final Closed-In Pressure" is taken by closing in the well with packers still seated, permitting the formation to continue to produce, thereby recording a build-up pressure curve.

FORMATION TESTING SERVICE REPORT

The Chart is given special reading (Figure 2), then reproduced and these then mounted into a "Formation Testing Service Report Folder," (Figure 3). Some uses which have evolved from these data:

A. Static Formation Pressure
B. Effective Permeability of the Zone Tested
C. Skin Effect or Damage Factor
D. Production Indices on Flowing Wells

TECHNICAL DATA TO CONSIDER FOR BEST RESULTS IN OPEN HOLE DRILL STEM TESTING

There are several not-so-well-known conditions that affect the operation of testing to such an extent that they cannot be ignored if maximum performance from testing tools is expected. One of these conditions is the loading on anchor piped during a drill stem test. The use of the Halliburton Pressure Equalizer will reduce anchor loading. The following examples show the desirability of running the pressure equalizer and in some cases the Side Wall Anchor Assembly to Straddle Test formations.

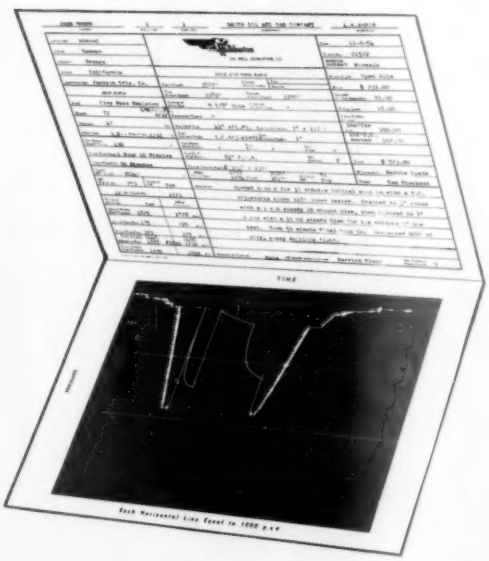


FIGURE 3

FIGURE 2

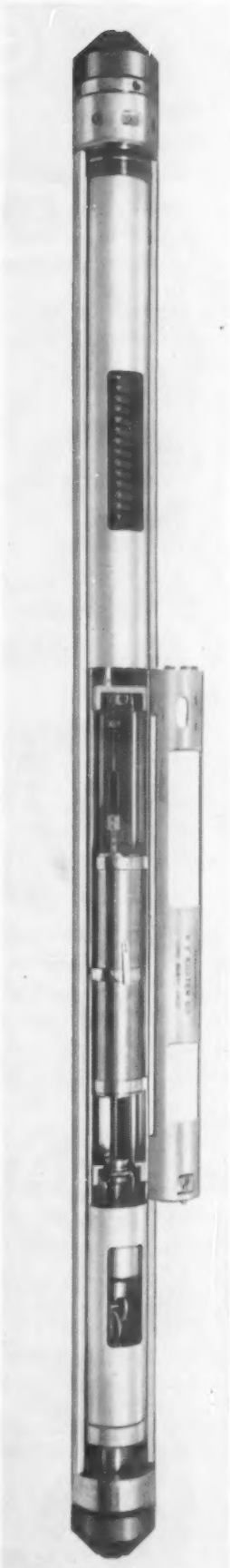


FIGURE 1

THE PRESSURE EQUALIZER

This device equalizes the pressure below the bottom packer with that above the top packer by use of a sealed off tube running through the packers. The Side Wall Anchor Assembly is a device with large slips that contact the wall of the hole and support the mechanical weight required to set the packers, eliminating the anchor pipe.

Here is an example of a well to be tested:

1. Total Depth . . . . . 10,200'
2. Formation to be tested — 195' off bottom, 10' section (unproductive)
3. Mud Weight . . . . . 9.6 lbs./gal.
4. Drill Pipe — 4½ API Full Hole 21.9 lbs./ft. (4½ — 20# with Tool Joints)
5. Size Drilled Hole — 8¾".

Using the above data, the following conditions will exist:

1. Hydrostatic pressure at the packers
   p = Mud wt. × .052 × depth.
   p = 9.6 × .052 × 10,000 = 5,000 psi.
2. Area of 8¾ hole = 60.13 sq. in.
3. Area of O.D. of Drill Pipe = 15.90 sq. in.
4. Area of wall of Drill Pipe = 5.5 sq. in.
5. Area of annular space between drill pipe and well bore = 44.23 sq. in.
6. Actual wt. of 10,000 ft. of 4½ drill pipe = 219,000 lbs.
7. The weight of the drill pipe as shown on the weight indicator with testing valve closed and packers not set:
   = Actual weight — buoyancy effect of hydrostatic pressure on O.D. of Drill Pipe
   = 219,000 — (5,000 × 15.9) = 139,500 lbs.
8. The weight of drill pipe used to compress the packers = 20,000 lbs.
9. Area of O.D. of Pressure Equalizer = .88 sq. in.
10. Area of anchor pipe wall = 8.2 sq. in.

If the formation is tested with a single packer as shown in Figure 1, the weight on the anchor would be 320,650 lbs. — a terrific column loading placed on the long anchor. This loading can be seen by referring to Figure 1 and is derived as follows:

1. As the wt. indicator reading is 139,500 lbs. and the actual wt. of the drill pipe is 219,000 lbs., the buoyancy effect on the drill pipe is 219,000 less 139,500 = 79,500 lbs. When the testing valve is opened the anchor pipe has to assume the 79,500 lbs. that was originally supported by hydrostatic pressure.

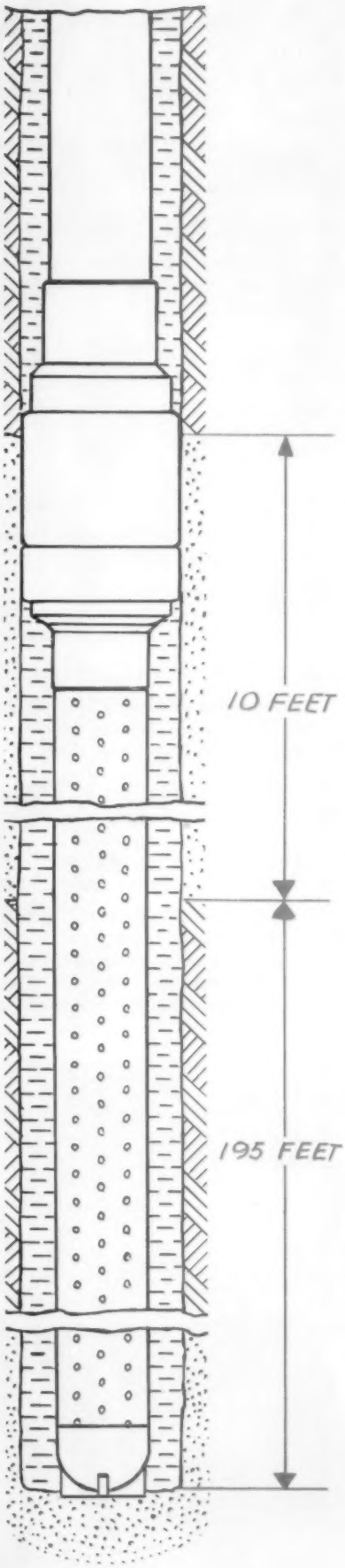


FIGURE 1

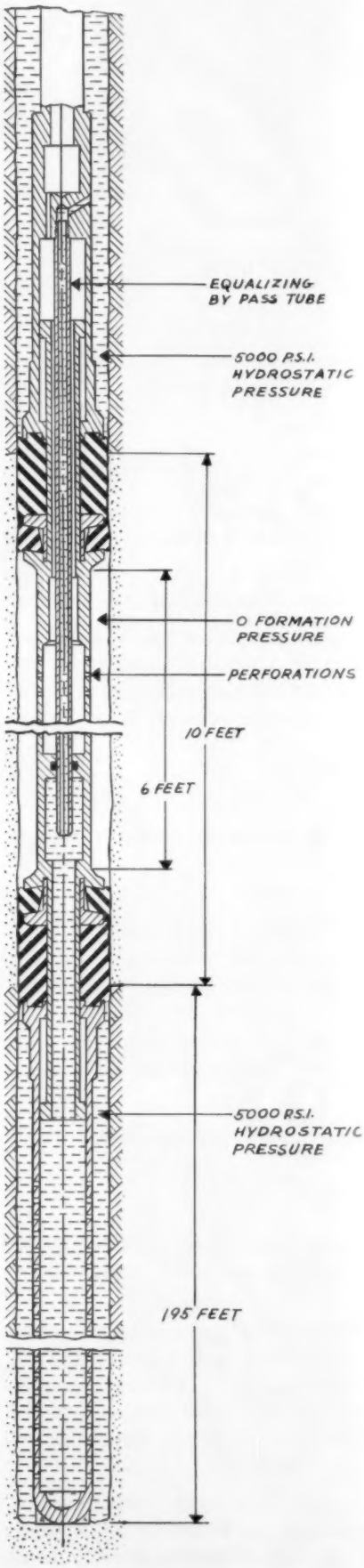


FIGURE 2

2. The total weight on the anchor is, therefore, the weight of the mud column between the drill pipe and the well bore, plus 79,500 lbs., plus the 20,000 lbs. required to compress the packers.

$$\text{Total wt.} = 44.23 \times 5{,}000 + 79{,}500 + 20{,}000 = 320{,}650 \text{ lbs.}$$

This equals the hydrostatic mud pressure times the area of the drilled hole, plus the weight required to set the packer.

$$\text{Total wt.} = 5{,}000 \times 60.13 + 20{,}000 = 320{,}650 \text{ lbs.}$$

The size drill pipe is not a factor when calculating the weight on the anchor.

If the same formation is tested with straddle packers using the pressure equalizer and anchor pipe, then the loading on the long anchor is 61,000 lbs. and the weight on the short spacer between packers is 316,250 lbs. This is derived as follows (refer to Figure 2):

1. When the tools reach bottom, packer compressed and the testing valve opened, the loading on the short perforated spacer between packers = hydrostatic pressure × annular area between drill pipe and well bore, plus the buoyancy effect of the hydrostatic pressure times the area of the O.D. of the drill pipe, minus the buoyancy effect of the hydrostatic pressure times the area of the O.D. of the pressure equalizer (which is still supporting part of the load), plus the weight required to compress the packers.

$$\text{Loading} = 5{,}000\ (44.23) + 79{,}500 - .88 \times 5{,}000 + 20{,}000 = 316{,}250 \text{ lbs.}$$

2. There is an upward force pushing up on the lower packer equal to the hydrostatic pressure times the area of the well bore, minus the hydrostatic pressure times the area of the anchor wall, minus the hydrostatic pressure times the area of the O.D. of the pressure equalizer:

$$= 5{,}000\ (60.13) - 8.2\ (5{,}000) - .88\ (5{,}000) = 255{,}250 \text{ lbs.}$$

3. The loading on the long anchor pipe below the packer is, therefore, 316,250 lbs. — 255,250 = 61,000 lbs.

If the hole size varies from one packer to the other, the loading will again be greatly affected, either to lessen or add to the anchor loading.

If the formation is now tested with the equalizer and the Side Wall Anchor Assembly, the loading on the slips is only the weight required to compress the packer, or in this case, 20,000 lbs. The weight supported by the short 6′ perforated spacer between the packers is the same as in Figure 2, or 316,250 lbs. Refer to Figure 3.

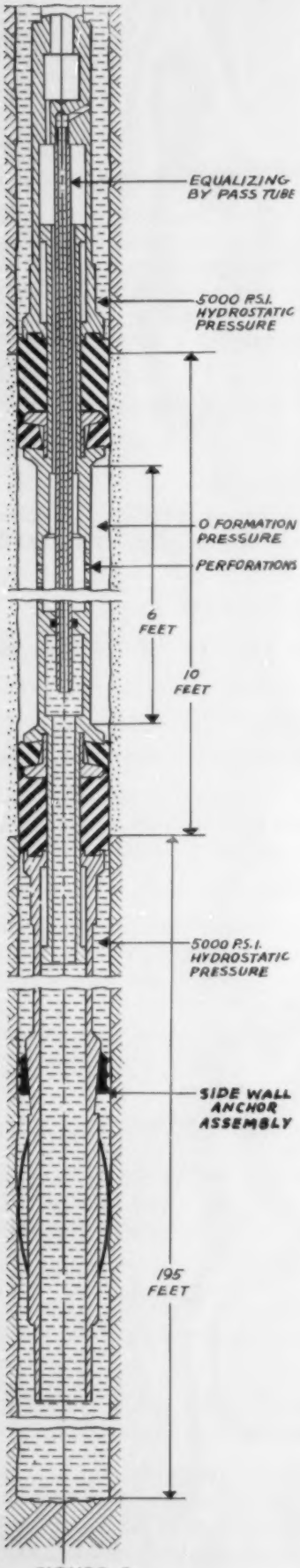


FIGURE 3

1. The force pushing upward over the bottom packer = area of hole bore × hydrostatic pressure, — area of the O.D. of pressure equalizer × hydrostatic pressure = 60.13 × 5,000 — 4,400 = 296,250.

2. The weight supported by the slips = 316,250 — 296,250 = 20,000 lbs.

Note that the forces are now being carried by the short 6′ section of anchor between the packers where the column loading is not nearly so effective. The above derivation of the forces acting upon the anchor pipe indicate the value of running straddle packers when testing an appreciable distance off bottom.

IMPORTANCE OF ADEQUATE BY-PASSING:

Adequate auxiliary by-passing is essential to prevent:

1. Damage to formation below the packer caused by excessive pressure build-up
2. Damage to the wall of the hole and/or packer

It is necessary to have an adequate by-pass to allow vertical transfer of fluids around the packer; thereby expediting the lowering and withdrawal of the testing string from the well bore. Adequate equalization greatly assists in the unseating of the packer.

Auxiliary by-passing is essential since the clearance between the packer and the well bore must be kept to a minimum. This further simplifies the packer passage through tight spots in the hole.

By-passes are a component part of Halliburton's Hydro-Spring Tester and VR Safety joints.

PACKER ABUSES IN OPEN HOLE:

The success of Open Hole Drill Stem Testing rests with the capability of the packer to seal off in a drilled hole and support the mechanical loads now encountered in deep well testing.

It is mandatory that maximum clearance between the packer support and the well bore be maintained to expedite the roundtrip necessary to perform the test. This is accomplished with the Halliburton Expanding Shoe. The packer support is expanded and reduces the clearance between the support shoe and the well bore, thereby minimizing extrusion (cold flow) of the packer during the testing period.

The elimination, or reduction, of the extrusion of the packer rubber over the support shoe reduces the danger of stuck packers and/or the leaving of rubber in the hole. Packer extrusion is caused by the high differential pressure across the packer while supporting the hydrostatic weight of the drilling fluid.

NEW AID FOR PRODUCTION

HV ACID

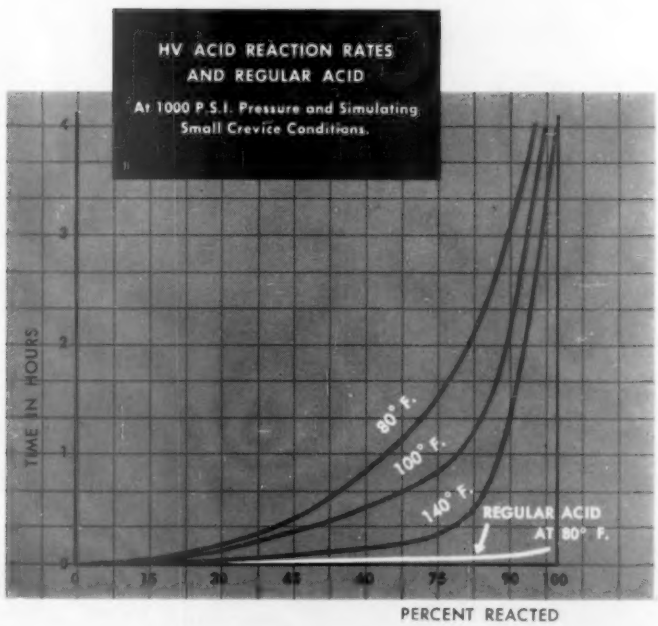
HYDRAULIC "BRAKE" ON CHEMICAL REACTION

A new Halliburton high viscosity mixture, HV Acid, provides slower, more effective acidizing for retreatments and automatic selective treatments. It temporarily plugs old permeable zones under low pressure pumping and diverts regular acids that follow into new flow channels.

The Chart shows typical reaction rates of HV Acid vs. Regular 15% Acid. Temperature alone without reaction does not decrease the viscosity of HV Acid. The rate is slow enough in most limestone or Dolomite wells to allow pressure build-up for following acid.

The delayed or retarded action is attained by holding the acid in a tight water-in-oil emulsion. Reaction is practically complete in 4 hours with loss of viscosity and there is nothing to interfere with back-flow to the well bore.

Through use of this acid diverting method, one company increased production by retreatments in 28 out of 31 wells where former attempts with ordinary acid had long been considered hopeless.



Your comments on this report will be appreciated. We hope you will find it interesting and helpful in your efforts to increase oil production. The five services reported on here are important, but, at Halliburton, research is our most important service.

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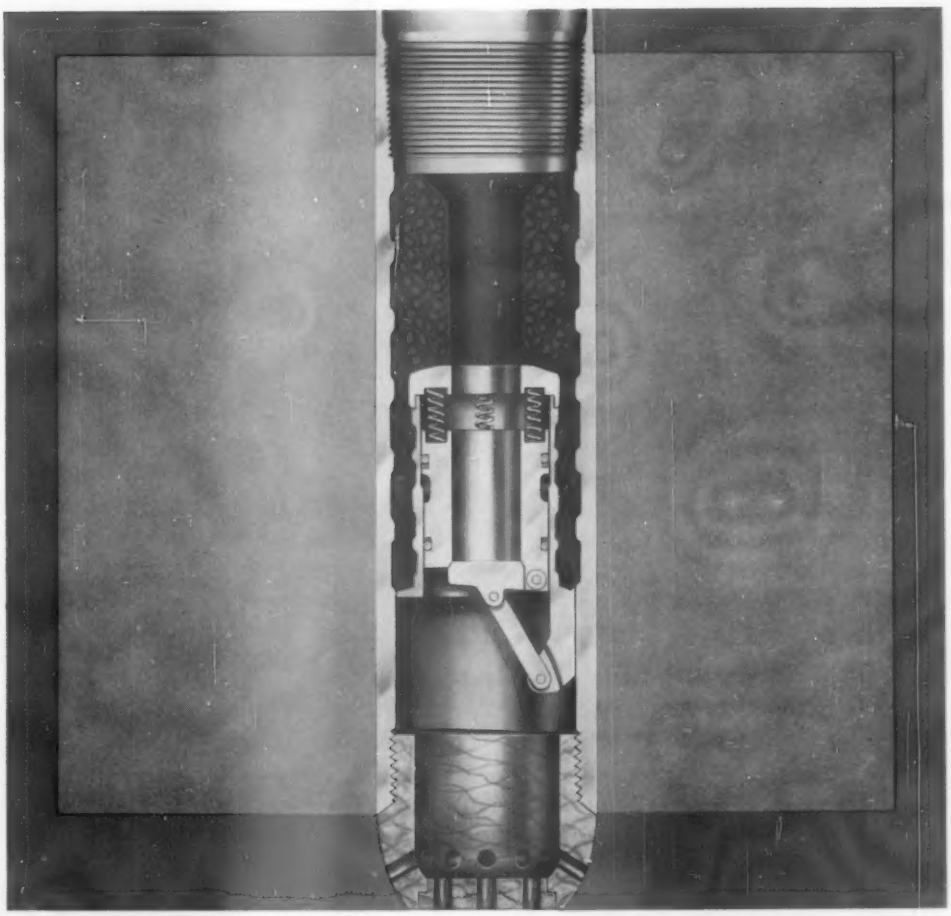
FILAMATIC FLOATING EQUIPMENT

for Automatically Filling Casing From the Bottom While Casing Is Being Run



Purpose of Filamatic Floating Equipment

The primary purpose of Larkin's Filamatic Floating Equipment is the automatic filling of a casing string to a precalculated level while casing is being run in the hole. This automatic fill-up, among other things, allows a continuous casing run uninterrupted by time consuming fill-up operations at the surface.

Many other advantages accrue with a Filamatic casing run. The time saved by automatic filling materially reduces rig time costs. The possibility of sticking pipe while casing is stationary is significantly lessened. The "Piston Effect" of closed-end casing being lowered into the mud-filled hole is reduced to a degree that minimizes damage to mud cake and the danger of breaking down possible lost circulation zones.

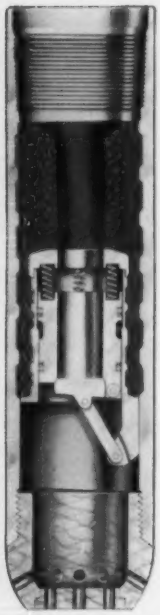


Fig. 306

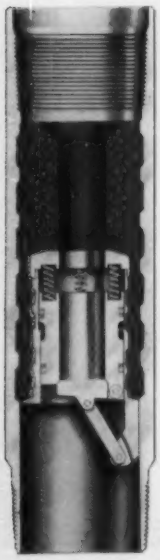


Fig. 406

CONSTRUCTION

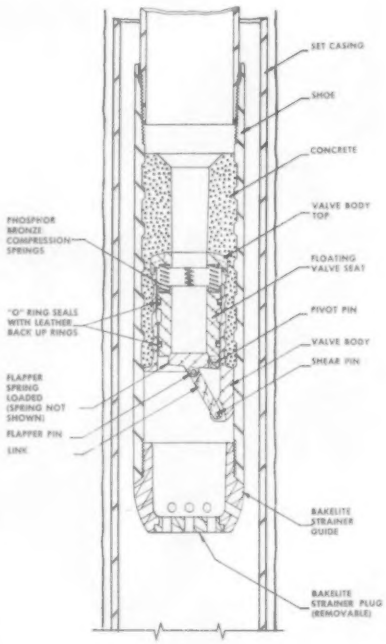
The mechanism of Filamatic Floating Equipment is manufactured from a heat treated aluminum alloy and consists of a cylindrical floating valve seat with a flapper valve pivotally mounted in its lower section. The flapper valve is pivotally linked by a pin to an extension of the valve body which is securely anchored in the concrete section.

The bottom surface area of the floating valve seat is 93.5% of its top surface area. The floating valve seat is spring loaded to overcome the "O" ring sealing friction permitting immediate functioning of the Filamatic valve even before sufficient depth has been reached to allow the fluid pressures in the well to actuate properly the Filamatic mechanism.

The Larkin Filamatic Float Shoe, Fig. 306, is equipped with a strainer shoe guide. This guide strains the fluid entering the shoe preventing the entrance of foreign material which might interfere with the proper functioning of the Filamatic mechanism. A strainer disc is pinned into the lower section of the shoe guide and will shear out when circulation is started. The required shearing pressure is approximately 200 P.S.I. The strainer disc may be removed prior to running-in where it is reasonable to believe the mud is not contaminated with large chunks of foreign matter, or where a very heavy mud is being used to prevent lost circulation.

The Larkin Filamatic Float Collar, Fig. 406, may be used with a regular guide shoe but the use of the Strainer Guide Shoe, Fig. 207, at no extra cost, is recommended.

If both Filamatic Float Shoe and Filamatic Float Collar are used, their effect on the amount of fill-up is compounded and the total fill is reduced to approximately 87.5%. The additional "floating effect" thus gained and the additional safety of having two back-pressure valves available makes the use of dual Filamatics desirable under certain well conditions.



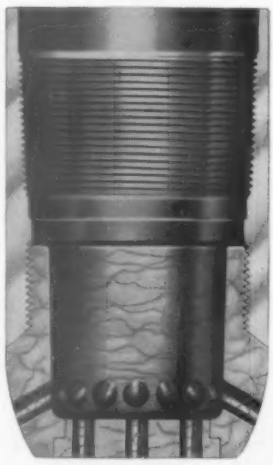


Fig. 207

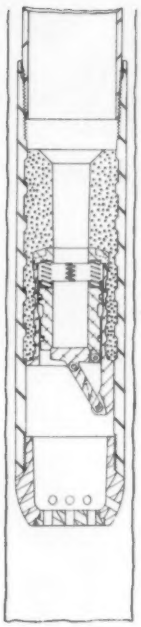


Fig. 1

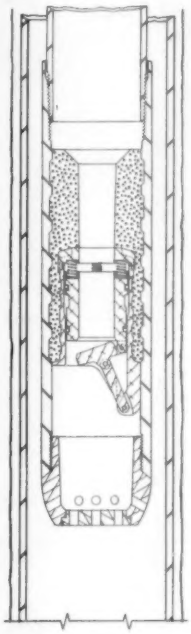


Fig. 2

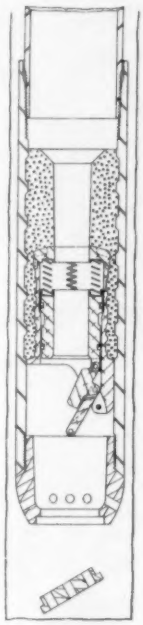


Fig. 3

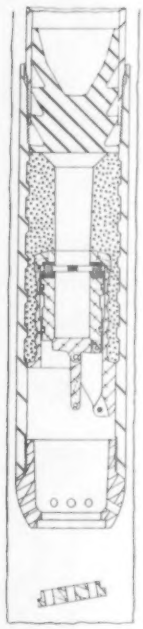


Fig. 4

OPERATION

When casing is started in the hole the Filamatic valve, urged by spring pressure, is in the closed position. (Note Fig. 1). As casing is lowered the annular fluid pressure soon overcomes the force of the springs and the floating valve seat slides upward. The link restrains the flapper valve, causing it to open and allow entrance of fluid into the casing. (Note Fig. 2). When the entering fluid fills 93.5% (87.5% with dual Filamatics) of the casing its pressure, acting against the greater surface area at the top of the floating valve seat overcomes the pressure being exerted on the lesser surface area at the bottom forcing the floating valve seat down into contact with the flapper valve as illustrated in Fig. 1. This action is repeated as casing is run to total depth.

Before cementing operations are started circulation is gained by filling the unfilled casing and pressuring up on this fluid column to approximately 900 P.S.I. This pressure is applied to the top surface area of the floating valve seat and the upward flat surface area of the flapper valve. The resultant downward force which is transferred to the lower link pin is sufficient to shear the link pin and free the flapper valve from the valve body. The flapper valve is now free to open and close, allowing unrestricted circulation through the casing and preventing return-flow of fluid into the casing. (Note Figs. 3 and 4).

Special attention is called to the full, undivided opening through Larkin Filamatic Floating Equipment. This opening permits a more efficient flow of fluid, minimizes the possibility of clogging and allows the passing of a bridging ball which may be dropped to actuate other equipment, such as Larkin Cementrol Equipment.

NOTES ON RUNNING FILAMATIC

Filamatic is designed for efficiency and is rugged in construction. Theoretically, as each joint of casing comes to rest in the slips the operator should be able to detect displacement of air as that portion of the joint which did not fill while being lowered is filling up. (This displacement of air can best be noted by placing a piece of cardboard with a small hole in it over the coupling of the joint just lowered.) Each joint lowered should displace from the annulus an amount of fluid equal to its own mass plus the amount of fluid that did not have an opportunity to enter a rapidly lowered joint.

It is possible that these results might be observed as each joint is lowered but there is no cause for concern if they occur at intervals of several joints. The rate at which casing is lowered as well as other individual well conditions can have effect on the surface indications of the performance of such equipment.

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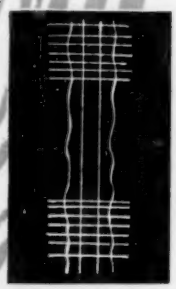

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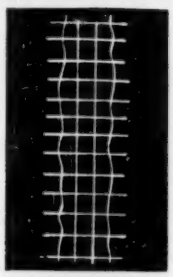

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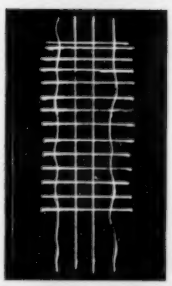
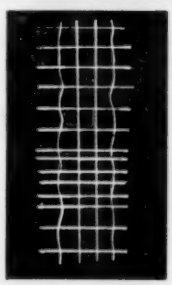


48 Shots in one 69" section.



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